CENTRE
DE RECHERCHE
SUR LES TRANSPORTS
(CRT)
CENTRE
FOR RESEARCH
ON TRANSPORTATION

UNIVERSITÉ DE MONTRÉAL
ÉCOLE DES HAUTES ÉTUDES COMMERCIALES
ÉCOLE POLYTECHNIQUE

C.P. 6128, SUCCURSALE A
MONTRÉAL (QUÉBEC)
CANADA
H3C 3J7

TÉLÉPHONE : (514) 343-7575
TÉLEX : 05-24146 BIBPOLYTEC
TÉLÉCOPIEUR (FAX) : (514) 343-7121

CRT-664

STRATEGIC PLANNING OF FREIGHT TRANSPORTATION: STAN, AN INTERACTIVE-GRAPHIC SYSTEM

by

Teodor Gabriel Crainic[1, 3]
Michael Florian[1, 2]
Jacques Guélat[4]
Heinz Spiess[1]

1 Centre de recherche sur les transports, Université de Montréal, C.P. 6128, Succursale A, Montréal, Québec, Canada H3C 3J7.

2 Département d'Informatique et de Recherche Opérationnelle, Université de Montréal, C.P. 6128, Succursale A, Montréal, Québec, Canada H3C 3J7.

3 Département des Sciences Administratives, Université du Québec à Montréal DSA-UQAM, C.P. 6192, Succursale A, Montréal, Québec, Canada H3C 4R2.

4 Université de Lausanne, Lausanne, Suisse.

This research was supported by a grant from the International Development Research Centre, the Natural Sciences and Engineering Council of Canada and from F.C.A.R., Québec.

Centre de recherche sur les transports - Publication #664

November 1989

90-01613/

Dépôt légal - 4e trimestre 1989

ABSTRACT

STAN is an interactive graphic system for national or regional strategic planning of multimode multiproduct transportation systems. We briefly describe the general concepts underlying the system, the data base structure, the assignment procedures and the results. Data and results from an actual application are used to illustrate these concepts.

KEY WORDS: Interactive graphic system, Multimode multiproduct assignment, Strategic planning.

RESUME

STAN est un logiciel interactif-graphique pour la planification nationale ou régionale des réseaux de transport multiproduit multimode. Nous décrivons brièvement les concepts généraux sous-jacents au système, la structure de la base de données, les procédures d'affectation et les résultats. Des données et des résultats provenant d'une application réelle servent à illustrer nos propos.

MOTS CLES: Logiciel interactif-graphique, Affectation multimode multiproduit, Planification stratégique.

STAN is an interactive-graphic multiproduct multimode method for national or regional strategic analysis and planning of freight transportation. The strategic level of planning implies a medium to long term time horizon and a rather aggregate level of detail for the representation of the transport services provided. The contemplated alternatives usually represent anticipated (or predicted) changes in the origin to destination demands for the products considered or major changes to the transportation infrastructure. At the strategic level of planning, the aim is to obtain an overall estimation of the movements of freight of most (or all) products, by most (or all) of the modes available; thus tactical decisions (such as when to schedule the trains that are operated) are not considered at this level.

A typical use of STAN is the comparison and evaluation of alternatives. Usually, an existing situation is described by one of the scenarios of the data base (base scenario). A simulation of the freight flows is carried out. Future situations are described by other scenarios which are constructed and contained in the data base. The simulation of freight flows are carried out on these scenarios as well. Then flows, link costs and delays, intermodal shipments and other performance indicators may be compared to those of the base scenario in order to carry out various analyses and comparison evaluations.

STAN is an interactive-graphic system specially designed for the strategic planning of freight flows at the national or regional level. The system offers a comprehensive and flexible modeling framework coupled with up-to-date algorithmic techniques and powerful computing capabilities. It allows the planner to engage in the planning process by using terminology that he is familiar with and obviates data processing type of tasks. Once the data base is set up, the planner needs not know or concern himself with the technical details of computer programming or computer systems. It also permits him the instantaneous visualization of input data, results of computations

and information retrieved from the data base, all in graphic or list form.

The goal of this paper is to describe the main features of the system. Section I describes the general concepts that underly the design of STAN, while Section II presents the most relevant characteristics of its implementation. Section III illustrates, by showing an example of actual application, the features and capabilities of STAN. We conclude this paper with a discution of the relative advantages of STAN as compared to other planning methods, and a brief enumeration of planned developments and functional enhancements of STAN.

I. GENERAL CONCEPTS THAT UNDERLY THE DESIGN OF STAN

The STAN system is composed of a series of modules used to input, modify, display and output information pertinent to strategic analyses of multimode multicommodity transportation networks. All data may be entered and modified either in batch or interactively; while using the second alternative, graphic work sheets are provided for entering network data. Figure 1 gives a schematic representation of a STAN data base, while Figure 2 presents the list of modules currently making up the system. Both are helpful in clarifying the descriptions that follow.

In STAN, the data that may be entered, modified and used for calculations falls into three main categories: networks, matrices and functions. The **network** data may be entered, modified and displayed by using the *Network Editor*. The *Matrix Editor* performs the same operations for **matrices**, and provides as well facilities for matrix calculations and matrix balancing. All the relevant **function classes** and **functions** are entered and evaluated by the *Function Editor*. The STAN data base may also contain **demarcation lines**, **utility data** and a **log book**, which we refer to as the **auxiliary data**. Demarcation Lines may be superimposed on

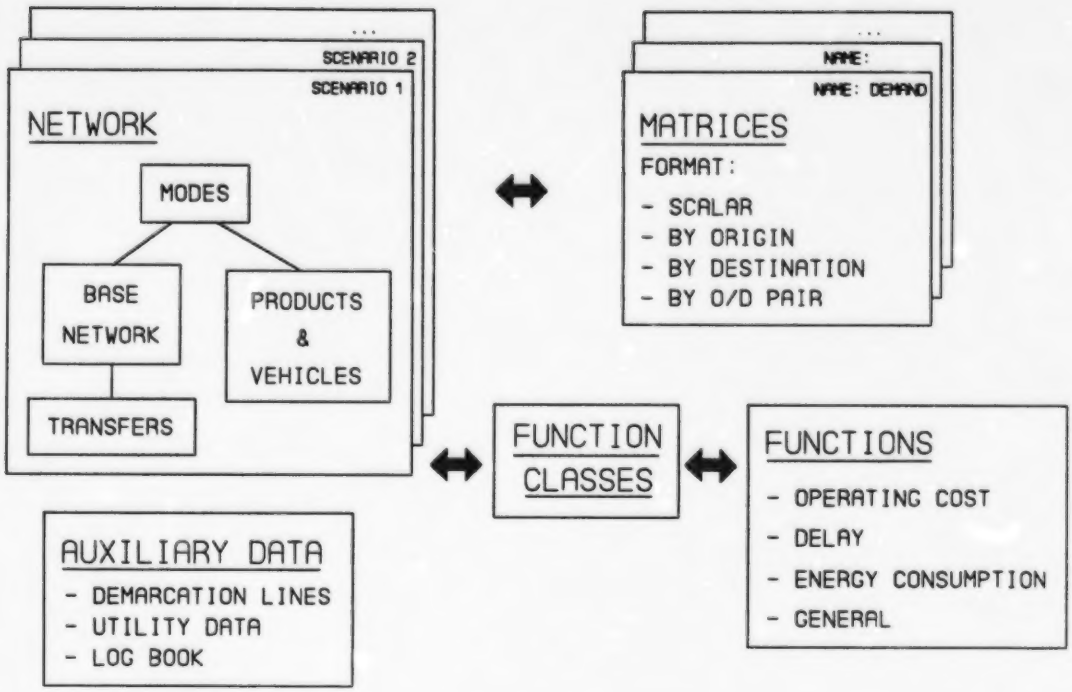

Figure 1 STAN Data Base

graphic displays to make them more readable. Utility data contain titles, module parameters, predefined windows, etc. A Log Book keeps track of the use made of the various STAN modules.

Brief descriptions of the **Networks**, **Matrices** and **Functions** that may be entered and manipulated by STAN are given in the following sections.

```
1.   U T I L I T I E S
1.11 Direct data base manipulations
1.21 Log book consultation
1.22 Scenario manipulations
1.23 Input / modify / output utility data
1.31 Input          demarcation lines using batch entry
1.32 Input / modify demarcation lines interactively
1.34 Output         demarcation lines
2.   N E T W O R K   E D I T O R
2.01 Input / modify / output modes
2.02 Input / modify / output products
2.11 Input          base network using batch entry
2.12 Input / modify base network interactively
2.13 Plot           base network
2.14 Output         base network
2.21 Input          transfers using batch entry
2.22 Input / modify transfers interactively
2.23 Plot           transfers
2.24 Output         transfers
2.33 Plot shortest paths on network
3.   M A T R I X   E D I T O R
3.01 Input / modify / display zone groups
3.11 Input          matrices using batch entry
3.12 Input / modify matrices interactively
3.13 Plot           matrices
3.14 Output         matrices
3.15 Plot           matrix histograms
3.25 Matrix calculations
3.26 Matrix balancing
4.   F U N C T I O N   E D I T O R
4.01 Input / modify / display function classes
4.11 Input          functions using batch entry
4.12 Input / modify functions interactively
4.13 Plot           functions
4.14 Output         functions
5.   A S S I G N M E N T   P R O C E D U R E S
5.11 Prepare scenario for   assignment
5.21 Multiproduct multimode assignment
5.31 Maxflow calculations
6.   R E S U L T S
6.01 Result summary
6.13 Plot    product costs and volumes
6.14 List    product results
6.15 Plot    product vehicles and convoys
6.23 Compare product costs and volumes
6.33 Plot    shortest paths on network
9.   E N D   O F   S E S S I O N
```

Figure 2 Modules of STAN

1.1 The Networks

The transportation infrastructure that spans the region studied is represented by a multimodal network. The flows that can occur over this transportation network are described by specifying the products and the modes used for their transport. A **network scenario** is described by a set of **modes**, **products**, **vehicles**, **base network** and **transfers**. Any of this data may be modified, at any time, provided that the hierarchy of the data structure is respected, as shown in Figure 3.

A **product** is any commodity (collection of similar products), goods or passengers, that generates a link flow specifically associated with it. A **mode** is a means of transportation that has its own characteristics, such as vehicle type and capacity, as well as a specific cost function. Depending on the scope and level of detail of the contemplated strategic study, a mode may represent a carrier or a part of its network representing a particular transportation service, an aggregation of several carrier networks, or specific transportation infrastructures such as highway networks or ports.

The **base network** is defined by the list of all the nodes and all the links between those nodes. In STAN parallel links are allowed between two nodes with the convention that a single mode is allowed on a given link. A path may contain successive links of different modes only if transfers are specified between them. A **transfer** is defined at a node, as a sequence from the mode of the incoming link, via the node, to the mode of the outgoing link. Thus, **transfers** represent intermodal transhipments at nodes.

For each product, a vehicle type is specified for each mode. A **vehicle** is described by its weight, by the weight it can transport and by an optional convoy weight (used, for instance, to specify train length). The number of vehicle types equals the number

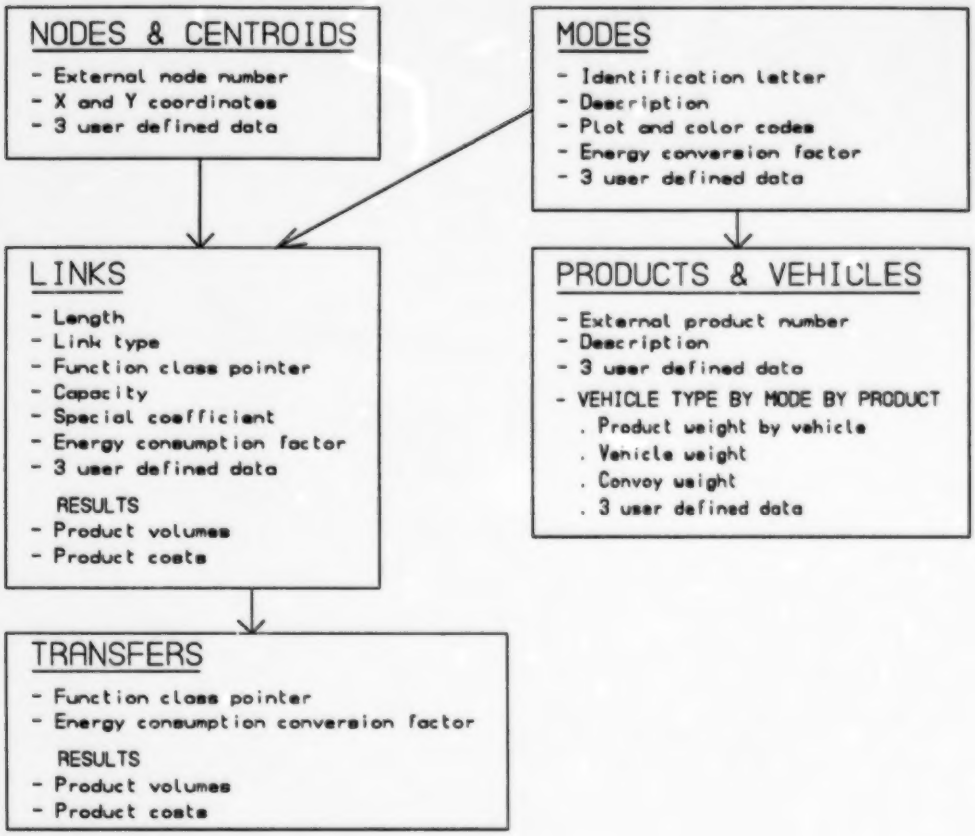

Figure 3 Network Scenario Hierarchy

of products multiplied by the number of permitted modes.

The user may specify up to three additional data elements for each **mode, product, vehicle, node** and **link**. Such **user data** may be observed flows or any associated data that the planner intends to use in subsequent analyses.

Each complete network data set (modes, products, vehicles, base network, transfers) makes up a **scenario**. The base period is one of these scenarios. The user may define a new scenario, by duplicating the data present in an existing scenario and

by making the appropriate changes in any one of the network data components. All these manipulations may be performed interactively, graphically when appropriate. In STAN, the network data that corresponds to a base period is not conceptually different from data of contemplated scenarios.

Various examples of modelizations of actual situations, performed by using this framework, may be found in (1), (2) and (3).

1.2 The Matrices

The **matrices** that are handled in STAN may be full matrices, origin or destination vectors or scalars. These may contain various data related to the zone subdivision of the area studied, such as origin/destination demand matrices, production by origin and attraction by destination. A matrix may be both an input to or an output from a computational procedure.

Matrices may be entered, modified and graphically displayed by using the *Matrix Editor*. The graphical display of the content of a matrix is performed by means of bars of width proportional to the value associated with an origin/destination pair or with a node, considered as an origin or a destination. Histograms, based on the contents of a matrix, may also be computed, compared and graphically displayed.

The *Matrix Editor*, which is the same as that of EMME/2 (4, 5), has been designed to permit the user to choose a matrix format that avoids duplication of data in the data base. For instance, if a full matrix has the same value in all its cells, then the user may specify only a scalar matrix as its value. The *Matrix Editor* will then use only the space required to keep the scalar, until a full matrix is requested in a STAN module. Then it will automatically expand the scalar value to a full matrix with that

value in all of its cells for the execution of that module. The same concept applies to given values for origins or destinations.

The *Matrix Editor* does not define any matrices by default. The definition of a matrix and its contents are left to the user. Thus, if an assignment routine expects the availability of origin/destination matrices, the user defines these matrices and ensures that they contain the correct data. This provides great flexibility in evaluating a given scenario with different O/D matrices.

Any network scenario created by the *Network Editor* may be used with any of the matrices present in the data base; the user identifies the relevant matrices that he wishes to use with a given scenario.

The *Matrix Editor* includes a module which permits the user to perform matrix calculations. The user specifies the operations that he wants to perform as an algebraic expression. Such algebraic expressions may be stated by choosing from 16 logical and algebraic operands and 9 intrinsic functions. The variables that may be used in these expressions are the matrices of the STAN data bank, centroid numbers and zone groups. The *Matrix Editor* of STAN also contains matrix balancing procedures in two and three dimensions. Their judicious use, with the appropriate matrices, permits the user to scale matrices or to implement some versions of classical spatial interaction (trip distribution) models.

For strategic planning purposes, the demand for transportation cannot be individually considered for each possible node of the network. This would generate unmanageably large origin/destination matrices and would explode both the model size and the computational time required by the algorithms, without improving the forecasts made. **Zones**, that contain several nodes in a contiguous geographical area, are defined and the transportation demand is aggregated accordingly. Each zone is

then represented in the network by a special node, called a **centroid**.

Whenever the *Matrix Editor* expects a zone number, a zone group can be specified, indicating that the operation applies to all zones within the group. A **zone group** is a set of zones. A set of zone groups that includes all the zones is called an **ensemble**. Within an ensemble, a zone may be in only one group. The user of STAN may specify up to 26 ensembles, each containing up to 100 zone groups. The advantage of using zone groups is that selection of subsets of zones may be accomplished efficiently, which is useful in many applications.

Most of the operations which involve matrices are usually performed on the entire matrix or on a submatrix defined by a subset of origins or a subset of destinations. In addition, the matrix elements to be considered may be selected by using a **constraint matrix** and a **constraint interval**. In this case, only those elements that correspond to elements of the contraint matrix that satisfy the constraint interval, will be considered.

1.3 The Functions

The **functions** that are used in STAN are subdivided into three types: operating cost functions, time delay functions and energy consumption functions. These functions may be specified for links and for transfers. The names, however, are only indications of some of the function types most widely used in actual practice; different functions may be used instead. The six functions associated with links and transfers are *unit cost* functions; they will be multiplied by the product volumes to form the total generalized cost function used in the assignment algorithm.

These functions are not part of the code and have to be specified by the user as

algebraic expressions by using the usual arithmetic and logical operators and intrinsic functions. Several keywords may be used as operands, each representing either a particular network attribute (vehicle characteristics, link properties, user defined data, etc.) or a specific combination of variables (total link or transfer flows, number of vehicles or convoys on links, etc.). When required, a function is evaluated with data that corresponds to the variables specified by the user in the algebraic expression that defines it. See (1) or (2) for particular functional forms, used in actual applications.

A **function class** is an index that associates to a link (transfer) a triplet of functions, an operating cost, a time delay and an energy consumption function, for each one of the products defined in the data base. Function classes are an efficient and compact way to associate functions to links and transfers. Several links (transfers) may share the same function class.

In addition to the types of functions described above, the user is free to define and display functions that are not employed in any of the standard calculations of STAN.

1.4 Assignment Procedures

The most general **assignment procedure** provided by STAN is a multimode multiproduct assignment method which minimizes the total cost of shipping the products considered, from origins to destinations, via the permitted modes (see (1) and Part II of (2)).

For each product, a subset of modes, which are permitted for a given assignment, may be specified. Moreover, the O/D demand matrix of a product may be split into several matrices for which subsets of permited modes may be defined, respectively.

This mechanism allows the introduction of predefined mode choices into the STAN system. It is always possible to assign all the products to all the modes, if desired.

The assignment does not permit explicit capacities on the network. Thus, when the services of certain modes are subject to capacity restrictions (e.g., rail, ports), these may be modeled as congestion and penalty functions, that are usually integrated into the delay cost functions (see Part II of (1)).

The assignment procedure may be carried out by using delay functions, in units of time, cost functions in currency units, energy costs in the appropriated units or generalized cost which may be a weighted combinations of time delays, operating costs and energy costs. The interaction between the flows of different products on different modes and its effect on costs is considered explicitly in the assignment procedure of STAN.

1.5 The Results

STAN permits the user to obtain a wide variety of **results** in interactive graphic form or as a printed output. The main feature of the results is the possibility of interactive comparison of scenarios with graphical displays. While the main results pertaining to comparisons of scenarios are related to flows and costs, a wide variety of other results may be obtained by using the user defined data. Section III illustrates many of these features.

Worthy of emphasis is that, unlike a "batch" code where each successful execution terminates with a particular, predifined set of results, an interactive graphic system allows the user to obtain results of different types (graphic displays, reports, plots, etc.) during a particular session. The notion of "result" is thus different from that of

a batch code and may be considered to consist of the entire gamut of displays, results of computational procedures, data bank queries and scenario comparisons.

1.6 Auxiliary Data

The Auxiliary Data consists of **demarcation lines**, **log book** and **utility data**.

The user may define **Demarcation Lines** that may be superimposed on a graphical output. A demarcation line may identify geographical characteristics of the area such as rivers or mountains, or certain regions of the country such as provinces, states, etc... .

A **Log Book** keeps record of the identity of the user and of the modules and elements of the data base used during all STAN sessions. The Log Book is not created automatically; this has to be done by the user.

Utility Data refers to certain data which are related to the use of STAN. These data may be transfered from one STAN data base to another to facilitate the construction of new data bases.

II. STAN - THE COMPUTER BASED SYSTEM

STAN has been coded in standard ANSI Fortran 77 and has been designed for easy transferability to various computer makes. It has been developed on a super-microcomputer (MC68000), however it has been adapted for IBM PC/XT or AT (and compatibles) equipped with the DSI-780 and PM-030 co-processor cards, and the SUN (MC68020) workstations. It may also be easily adapted for other computing environments. At present, STAN is implemented for use on a wide variety of graphic terminals which support the Tektronix protocol. It may also be used with several high resolution graphic adapters and suitable monitors on personal computers operating under MS-DOS. Plots created with STAN may be drawn on Calcomp, Hewlett Packard, Houston Instruments or Tektronix digital plotters. Plots may also be produced on dot matrix printers.

The code of STAN has a modular structure. Each one of the modules (see Figure 4) is an independent program, but all the modules share the STAN subroutine library. All data transfers between modules occur only via the data base. Figure 4 gives a schematic representation of the program structure.

Worthy of mention is the fact that STAN provides the user with a language aimed at building **macro** procedures (7). This language, which is the same as that used in EMME/2, is quite versatile; it allows, for example, to specifiy parameters that are replaced by actual data at execution time. This is a powerful feature, that may significantly facilitate the user' applications by substituing macro calls for sets of frequently used commands.

For additional details on the various STAN modules and interfaces, see Part III of (1) or (7).

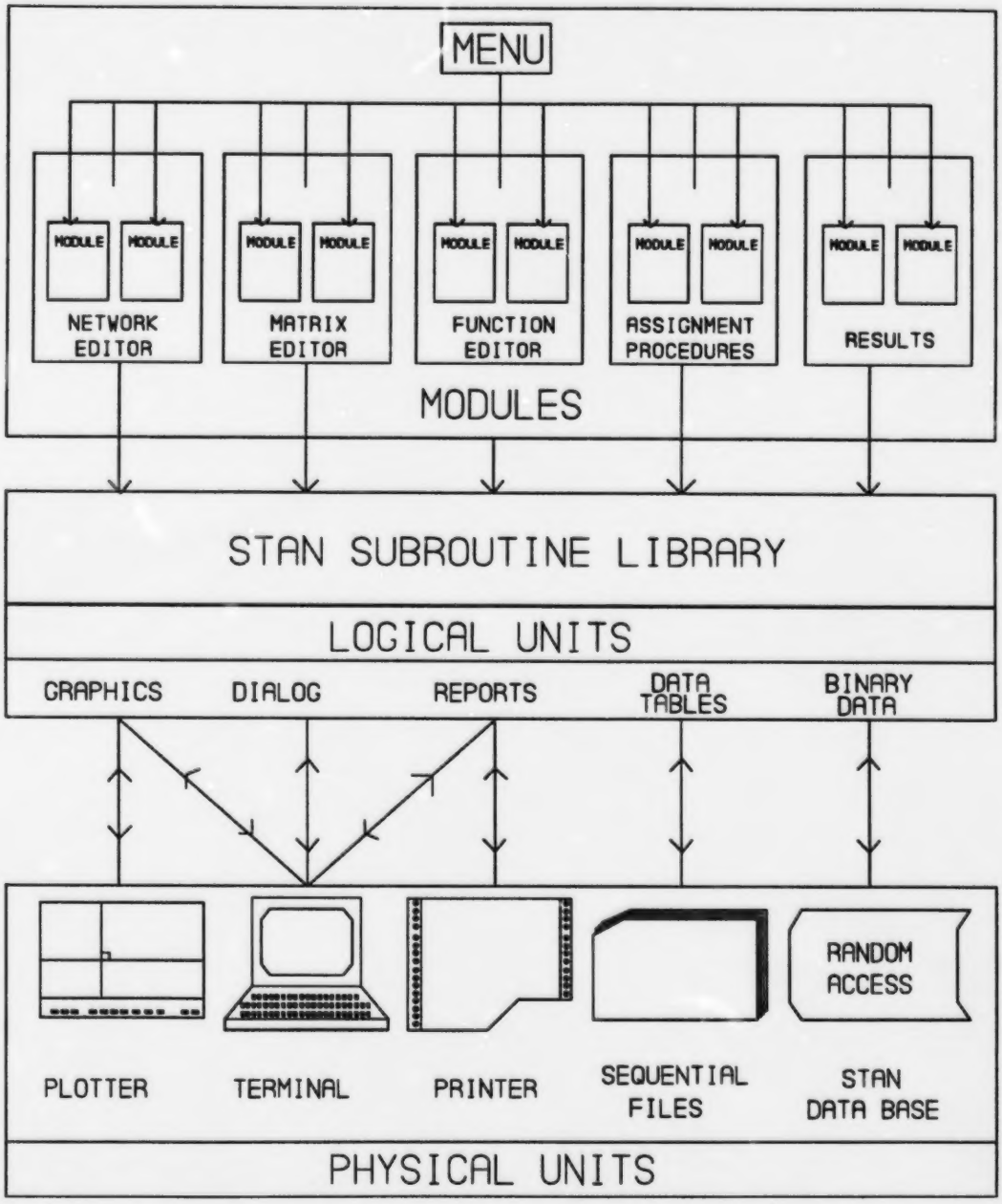

Figure 4 The Program Structure

III. APPLICATIONS

This section is dedicated to the presentation of an actual applcation, in order to illustrate the capabilities and potential of STAN for the modeling and analysis of national or regional multimodal transportation networks.

The object of this application was the study of the transportation network of the South-East region of Brazil. This region corresponds to the States of São Paulo, Rio de Janeiro, Minas Gerais and Espirito Santo (regions IV, V and VI of Figure 5) which represent the heart of the country with respect to all criteria: economics, demographic, social, political, etc.

Figure 5 also illustrates the utilization in STAN of **demarcation lines** to identify specific subregions and geographic features of a study area.

Ideally, the data necessary for constructing planning scenarios are determined in order to permit a policy sensitive representation and analysis of the system under study. In practice, one has to take into account the data available, the requirements of the modeling and algorithmic approach and also, the anticipated efficiency of the solution and evaluation methods of the available computer-based system. The collection of data is a multi-step process, that requires that choices be made at each step of developing the database for a particular application.

STAN requires data describing the components of the multimodal transportation network (modes, nodes, links, transfers) and their attributes (vehicles, lengths, capacities, unit costs, associated functions, etc.) and data quantifying the transportation demand that is to be shipped, on the permitted modes, from each origin to destination.

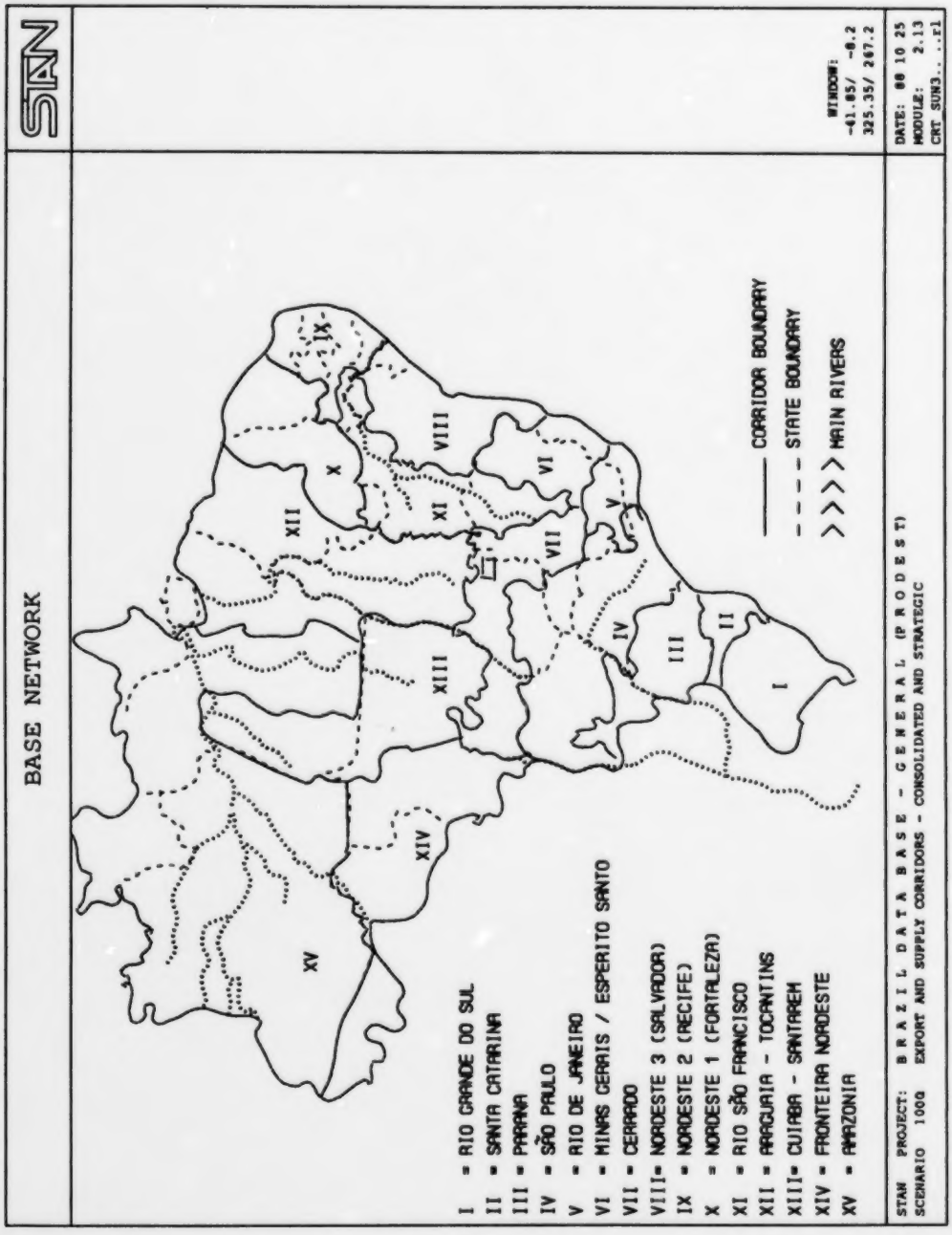

Figure 5 The Brazilian Regions

The first step in the definition of the data base for a new application, is to divide the region under study into traffic zones, and to associate a centroid to each zone. Zones are generally divided according to several criteria, such as homogeneity, concordance with natural boundaries and compatibility with the main available data sources. For the Brazilian applications, we have adopted the zone definitions used by GEIPOT, which is the planning agency of the Brazilian Ministry of Transportation.

The zones defined by GEIPOT served to subdivide the South-East region, while outside the region several groups of zones have been aggregated into, so-called, *External Zones.* To specify the External Zones, the zones in the other regions of the country that have significant trade flows with the South-East region were retained. The other zones were subsequently aggregated into appropriate groupings. Figure 6 illustrates the main connections between the study area and these External Zones.

The network for the South-East region application was defined by starting with a rather detailed network representation developed by GEIPOT. This network was subsequently aggregated, simplified and updated by using data from various governmantal organizations which operate or supervise railways, roads, ports, navigation operations. A list of the data sources, as well as numerous details on how data for this application was collected, validated, and represented in STAN may be found in Part IV of (1).

Ten modes were defined to represent the main transportation infrastructure of the region: five for rail (large or metric gauge with diesel or electric traction, plus a narrow gauge diesel traction mode), one for road, another for ports, and three for navigation (inland, coastal and ocean).

Figure 7 illustrates the final multimodal network; modes are identified by line pattern and by color when a color monitor is used. Node numbers may or may not

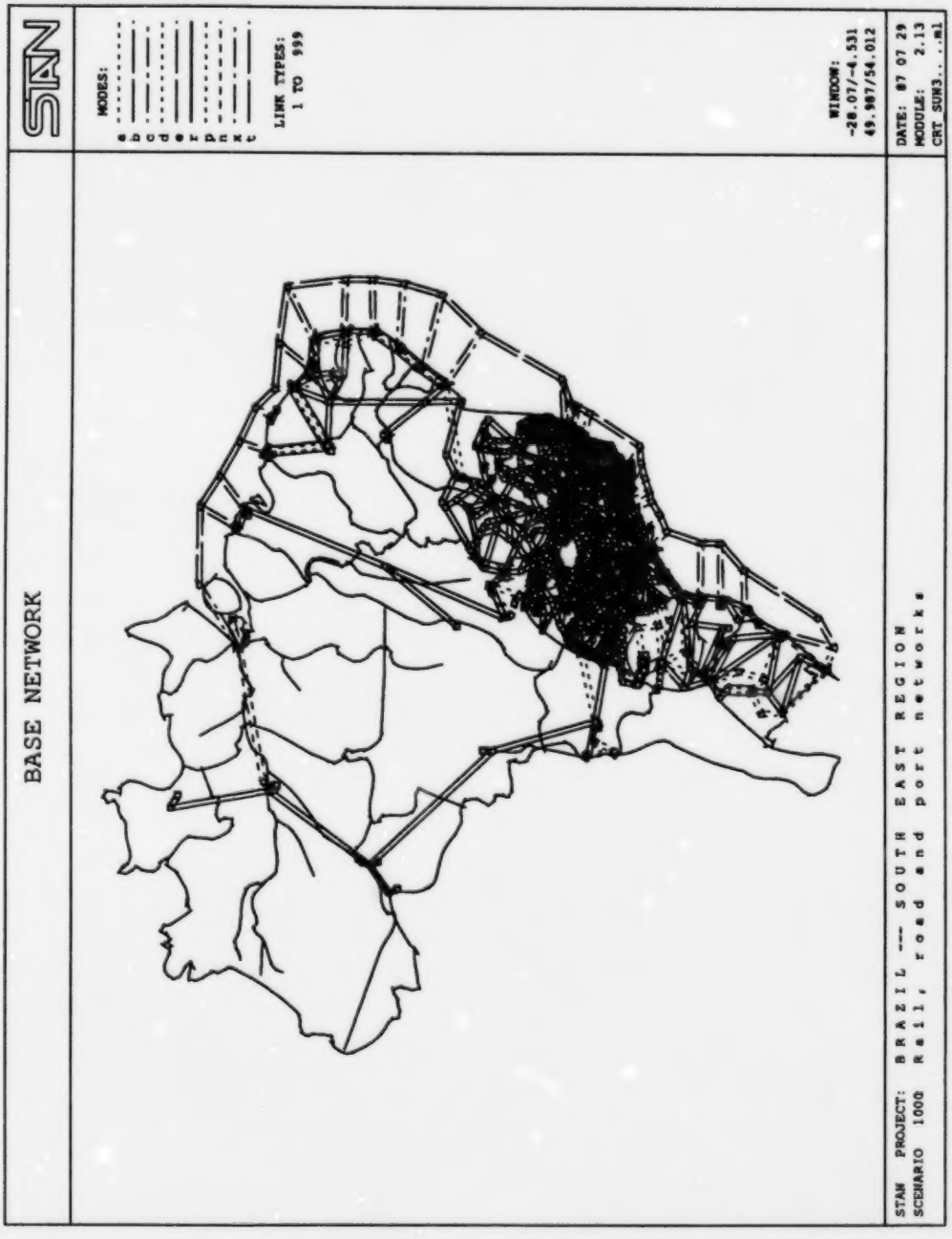

Figure 6 External Zone Connections

be displayed. When modes are not identified, the system displays the **bare network** (see Figure 9) that shows all possible connections in the network.

An important part of the network definition process has been its interactive-graphic validation. By using the graphic capabilities of STAN, Brazilian technicians, which knew the network well, could focus on relatively small areas, one at a time, and by using the graphic work sheet, modify any error they found. Figure 8 illustrates the use of the graphic work sheet to interactively modify the base network: node 9999 and the links between it and nodes 1441 and 1990 have been added, by using the "Reg. Nodes", "Add", "Links" and "Use same Data" commands.

Transfers have been similarly displayed, analyzed and, eventually, modified by using a graphic work sheet similar to the one previously presented for the base network. Figure 9 illustrates how transfers may be graphically selected (this may be performed on either the bare or the base networks), while Figure 10 displays the plot of a transfer. Several transfers may be simultaneously displayed on the same plot.

In order to complete the specification of the transport services provided on this network, a variety of attributes had to be defined. These include the characteristics of the typical vehicles that transport each product on each mode, the physical characteristics and the functional forms for the transportation delay, costs and energy consumption for each link and transfer of the network. In particular, functions were used to model the impact of the condition of the road (unpaved, paved), of its horizontal alignment, profile and maintenance state on the operating costs, the energy consumption and the travel time of various vehicle types. Similar studies were conducted for the navigation modes. Appropriate functions were also used to represent the impact of limited infrastructure capacity and of congestion conditions on the traffic flows and productivity measures (costs, travel times, ...) for the rail and port modes. Figure 11 shows various examples of link and transfer delay functions for the

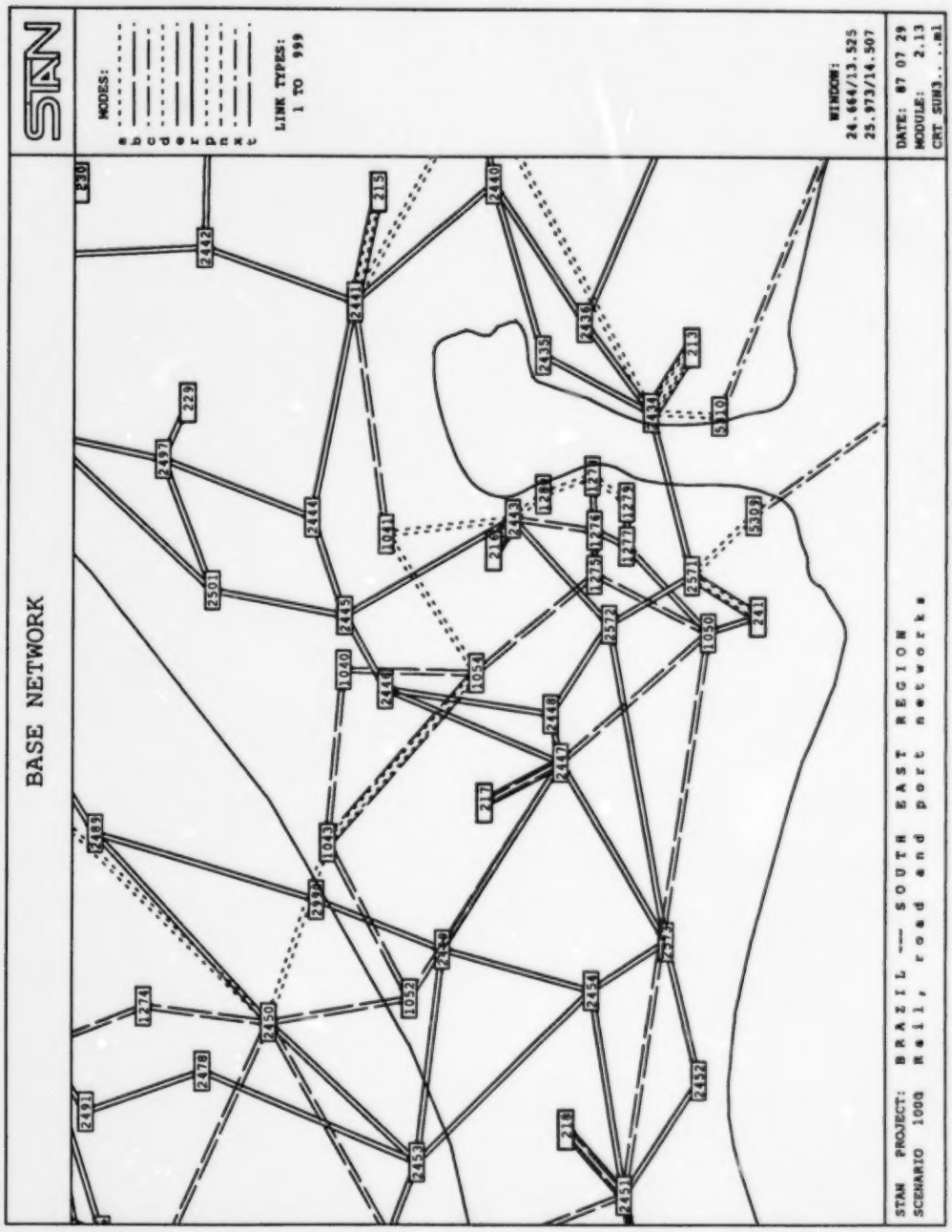

Figure 7 Multimodal Network Representation

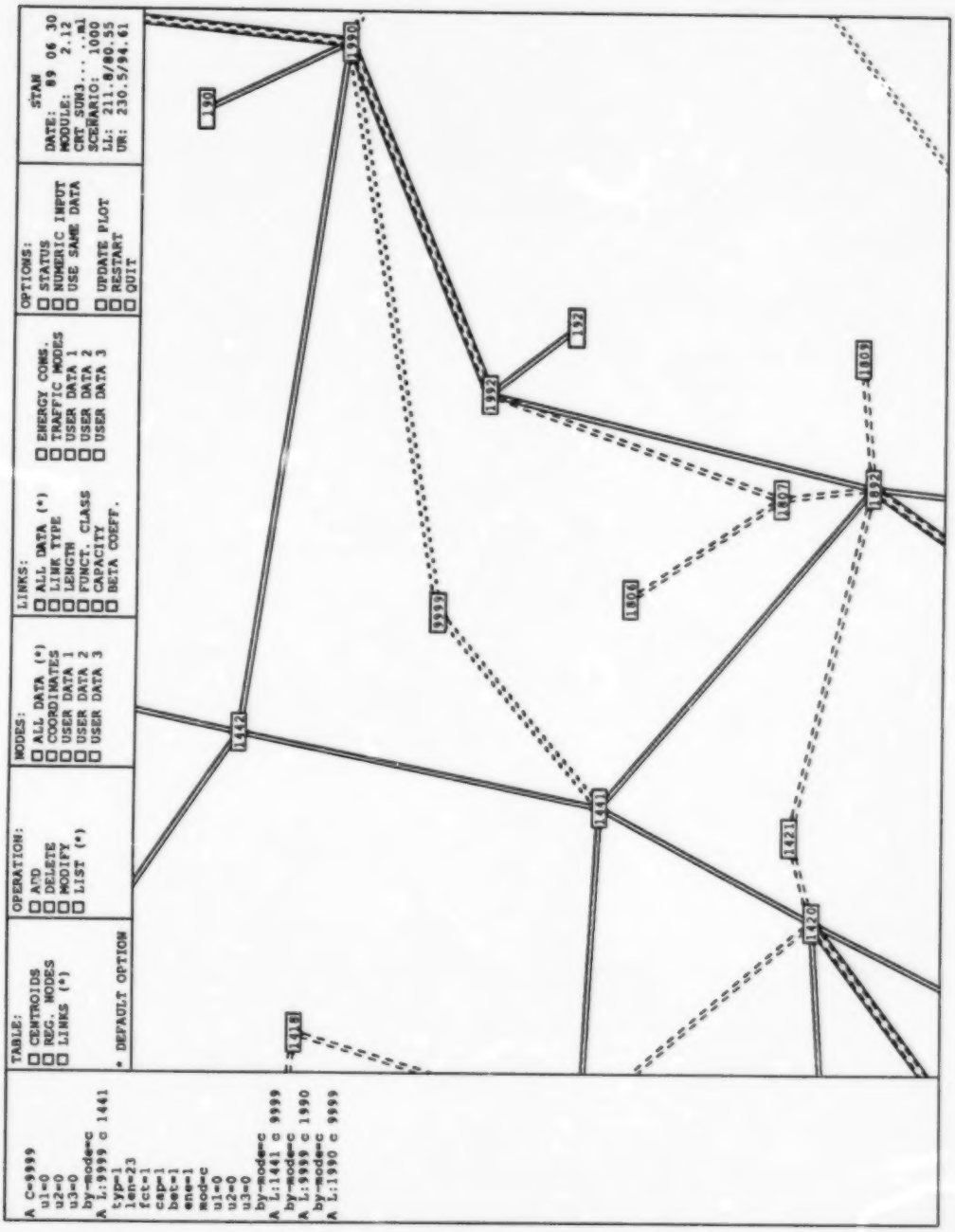

Figure 8 Graphic Work Sheet

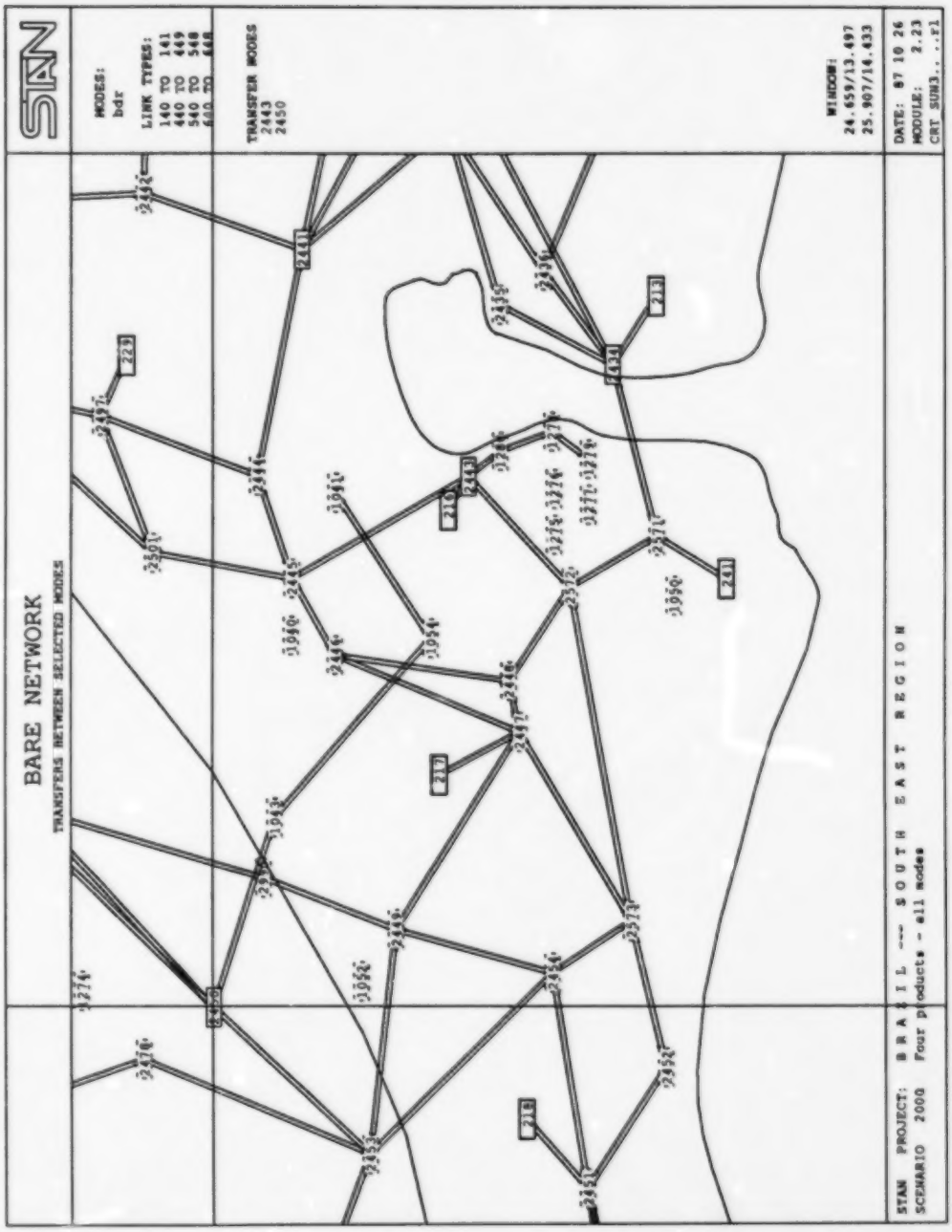

Figure 9 Interactive-Graphic Selection of Transfers

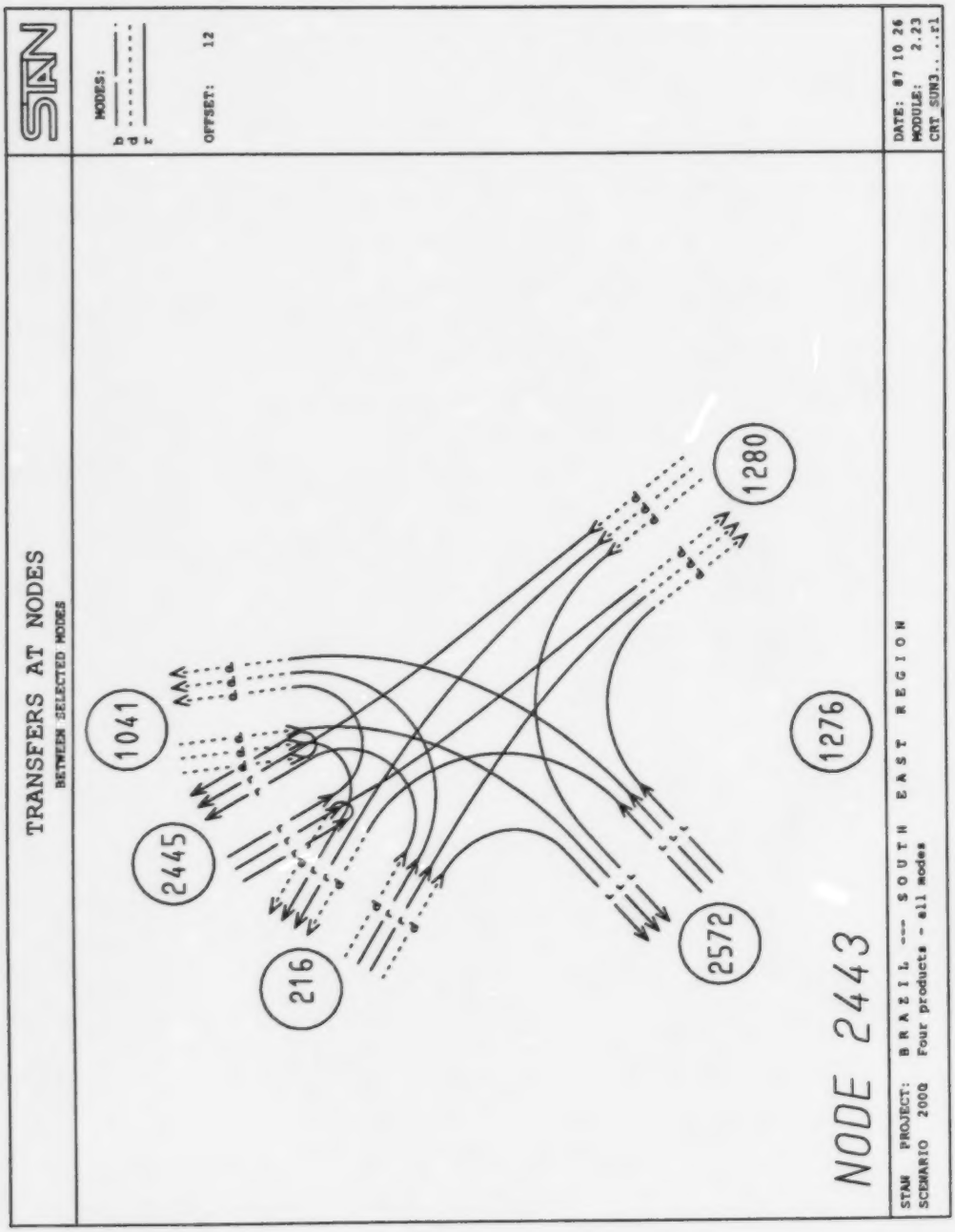

Figure 10 Plot of an Intermodal Transfer

rail modes, as well as the keywords of STAN that may be used to define them. Figure 12 displays the plot of a typical rail link delay function (such as fdl20 in Figure 11) for various capacities and congestion levels. This exercise required long, arduous and often frustating efforts, often due to the lack of homogeneity among the data sources and sometimes due to lack of reliable data.

Data that permits a meaningful visual representation of the network was also included, such as demarcation lines for the national and regional boundaries, as well as natural (rivers and mountains) or artificial (hydro-electric works) geographical features. Demarcation lines constitute a salient feature of most of the figures of this chapter, mainly Figure 5.

Building the origin-destination (O/D) matrices, containing the demand (in tons) of each product that was included in the study, could not have been successfully accomplished, within the time and budget resources of the project, without the help of existing data. In this respect, we were fortunate to have access to the O/D matrices that had already been estimated by GEIPOT.

For the purpose of the pilot phase of the project, 8 products, were chosen for validation purposes. These products were chosen for their importance and impact on the transportation system in the South-East region and are: iron ore, steel products, coal, cement, fertilizers, soya oil, soya grain and soya meal. These products generate the major flows on the links of all the modes present in the region.

These matrices were validated, updated and aggregated, according to the network definition of the application, by using the graphic and analytic tools provided by STAN.

Several graphical representations of matrix data were used: desire lines represen-

```
STAN  Module: 4.14          Date: 89 06 30          User: CRT_SUN3..ml          Page: 1120
Project:       SAN FRANCISCO REGION STUDY
-------------------------------------------------------------------------------------------

function definitions
--------------------


link delay                  ( length    cap       beta      ul1       ul2       ul3       volprod
                              conwgt    wbyveh    vehwgt    up1       up2       up3       voltot
                              vehprod   vehtot    train     strain    um1       um2       um3
                              ump1      ump2      ump3 )

fdl1   = (.01524 * ump1 + .01595 * ump2 + .01499 * ump3) * length

fdl20  = (length / ul2) * (1 + (1.10000002 / cap) * (strain *
         19.2300014) + 4.14400005 * (((strain * 19.2300014) / cap) ^
         6))

fdl30  = .067 * length

fdl40  = .08295001 * length

fdl50  = (.05) * (voltot .le. cap) + (.05 + 2 * (voltot - cap)) * (
         voltot .gt. cap)

fdl60  = (.05208301) * (voltot .le. cap) + (.05208301 + 2 * (voltot -
         cap)) * (voltot .gt. cap)

fdl70  = (.050505) * (voltot .le. cap) + (.050505 + 2 * (voltot - cap
         )) * (voltot .gt. cap)

fdl80  = (.03268) * (voltot .le. cap) + (.03268 + 2 * (voltot - cap))
         * (voltot .gt. cap)


transfer delay              ( volprod   voltot    up1       up2       up3       un1       un2
                              um3 )

fdt1   = .01815

fdt2   = .09091001

fdt10  = (.09090901) * (voltot .le. 100) + (.09090901 + 2 * (voltot -
         100)) * (voltot .gt. 100)

fdt20  = (.02907) * (voltot .le. 500) + (.02907 + 2 * (voltot - 500))
         * (voltot .gt. 500)

fdt30  = (.33333001) * (voltot .le. 500) + (.33333001 + 2 * (voltot -
         500)) * (voltot .gt. 500)

fdt40  = (.006916) * (voltot .le. 1500) + (.006916 + 2 * (voltot -
         1500)) * (voltot .gt. 1500)

fdt70  = 10
```

Figure 11 Link and Transfer Delay Functions

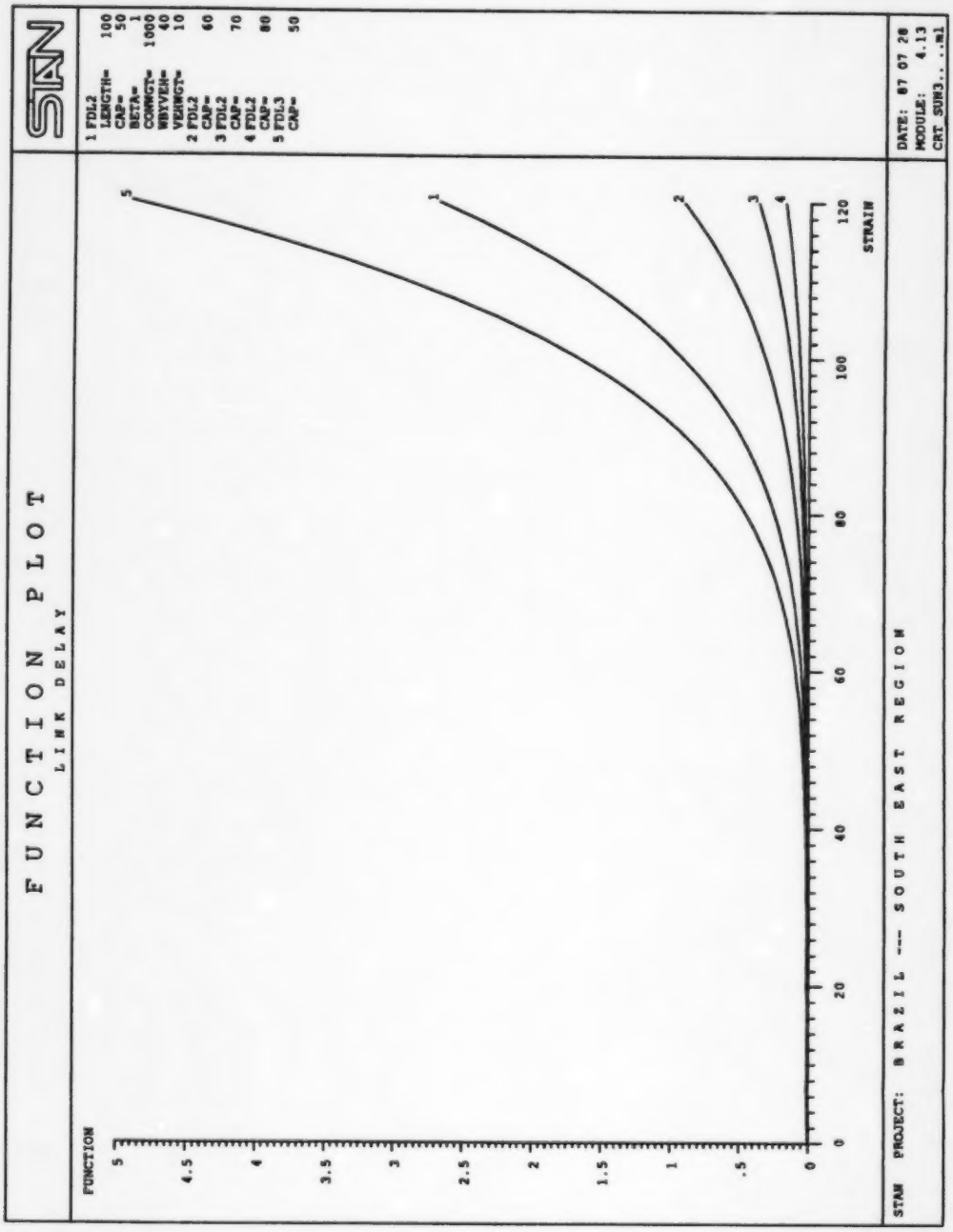

Figure 12 Rail Link Delay Function

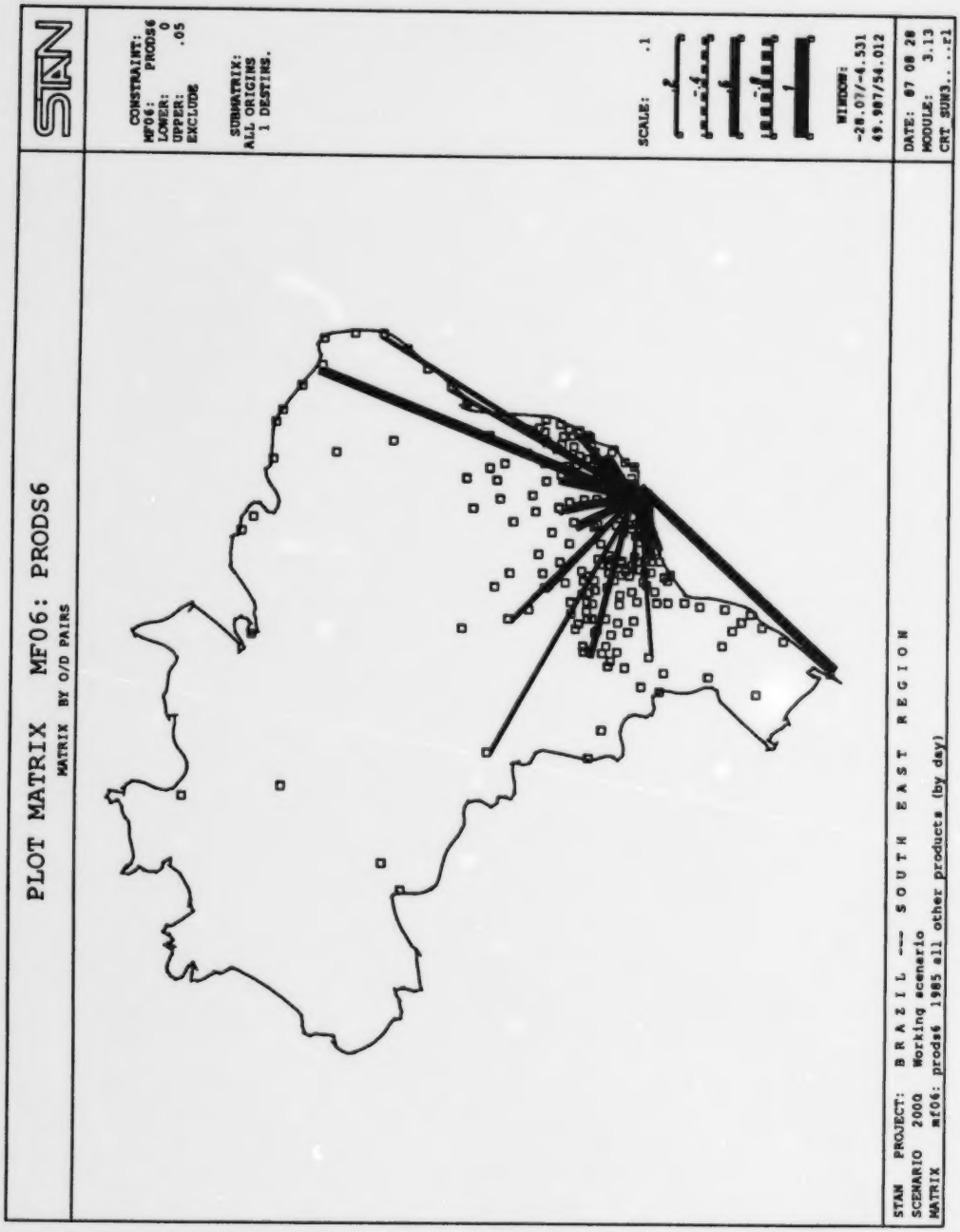

Figure 13 Matrix Plot-O/D Desire Links

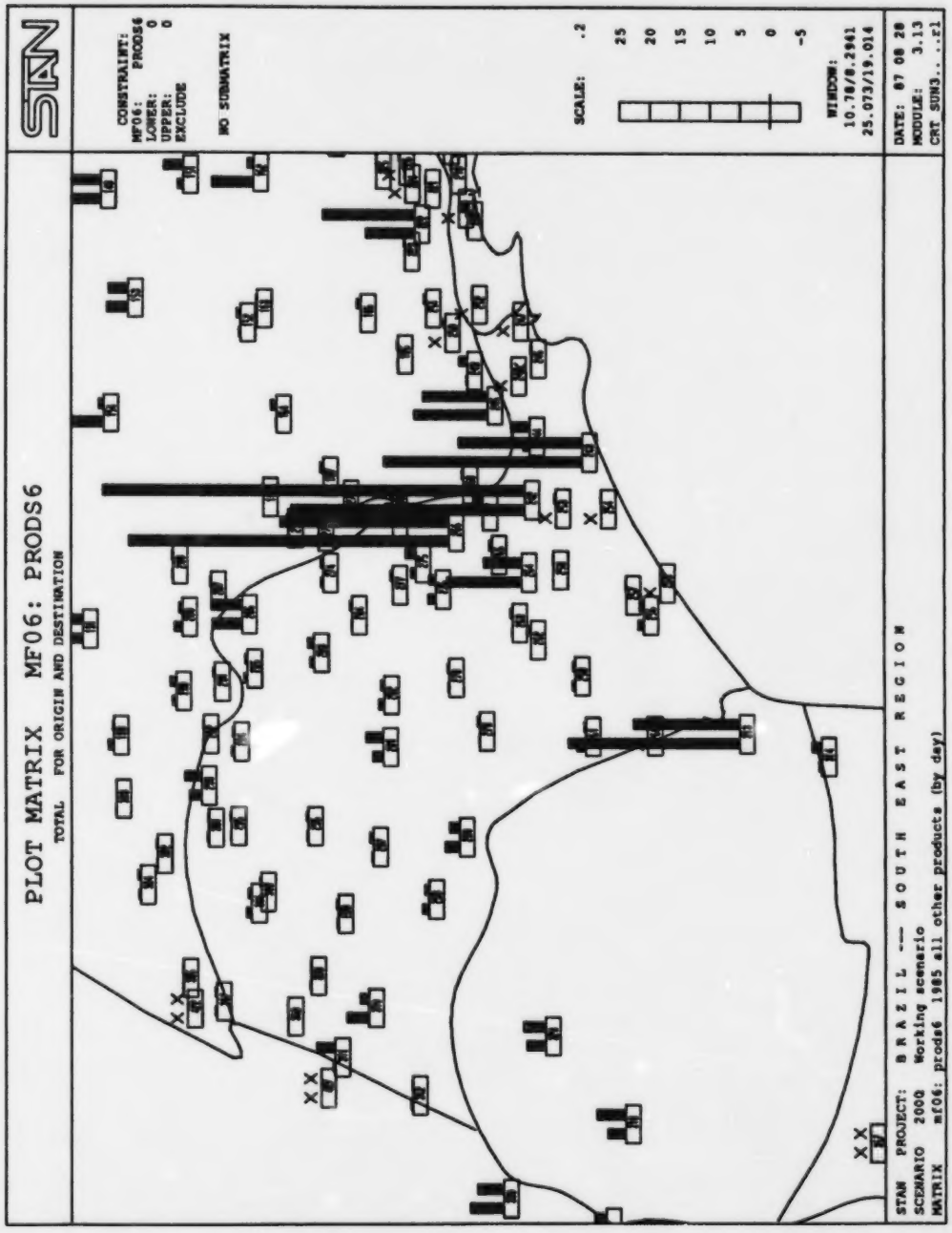

Figure 14 Zone Supplies and Demands

tating O/D transportation demands (Figure 13), chimneys proportional to the total supplies or demands or both (Figures 14 and 15), histograms, and histogram comparisons (figure 15), of density, or cumulative, of actual or normalized values (Figure 17).

The analytic tools provided by STAN were used to validate the sectorial interdependencies observed for the selected products, by answering the question: are the quantities of products arriving at a center sufficient to generate the final output of product, according to the transformation coefficients? For example, the matrix calculator was used to transform the matrices of the final products (e.g., soya meal and soya oil) into the matrices for the raw product (e.g. soya grain). These matrices were then added up; the result was aggregated by origin, giving the demand vector. The O/D matrix for the raw product was aggregated by destination giving the supply vector. The supply-demand differences were then computed and recorded. All these operations were performed by using the matrix calculator. The differences are displayed in Figure 16, and the corresponding histogram in Figure 17. The excess in the supply of soya grain indicated, in most cases, export flows by maritime ports. Deficits pointed to the need to verify the data, by consulting the industries that were involved. In the particular case of soya products, the differences were small and relatively easy to reconcile.

The matrix calculator and the matrix balancing procedures provided by the STAN *Matrix Editor* were also used to generate O/D demand matrices for intermediate years, starting from a base year O/D matrix and forecasted supplies and demands (see Figure 24). Similar procedures were also used to generate the O/D matrix for the empty car traffic that has to be considered on the rail modes (4). Additional information concerning the demand estimation and validation during this application may be found in (1).

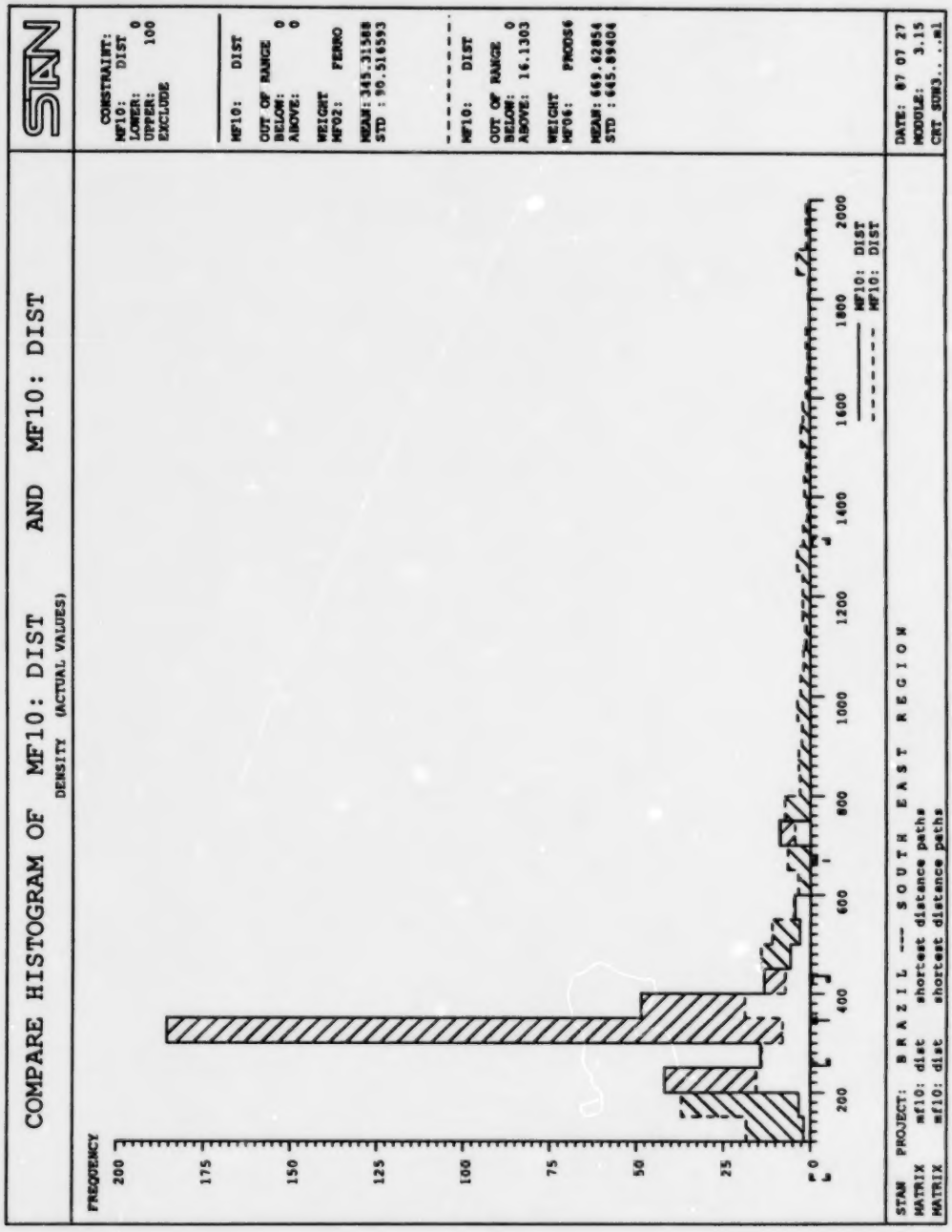

Figure 15 Comparison of Matrix Histograms

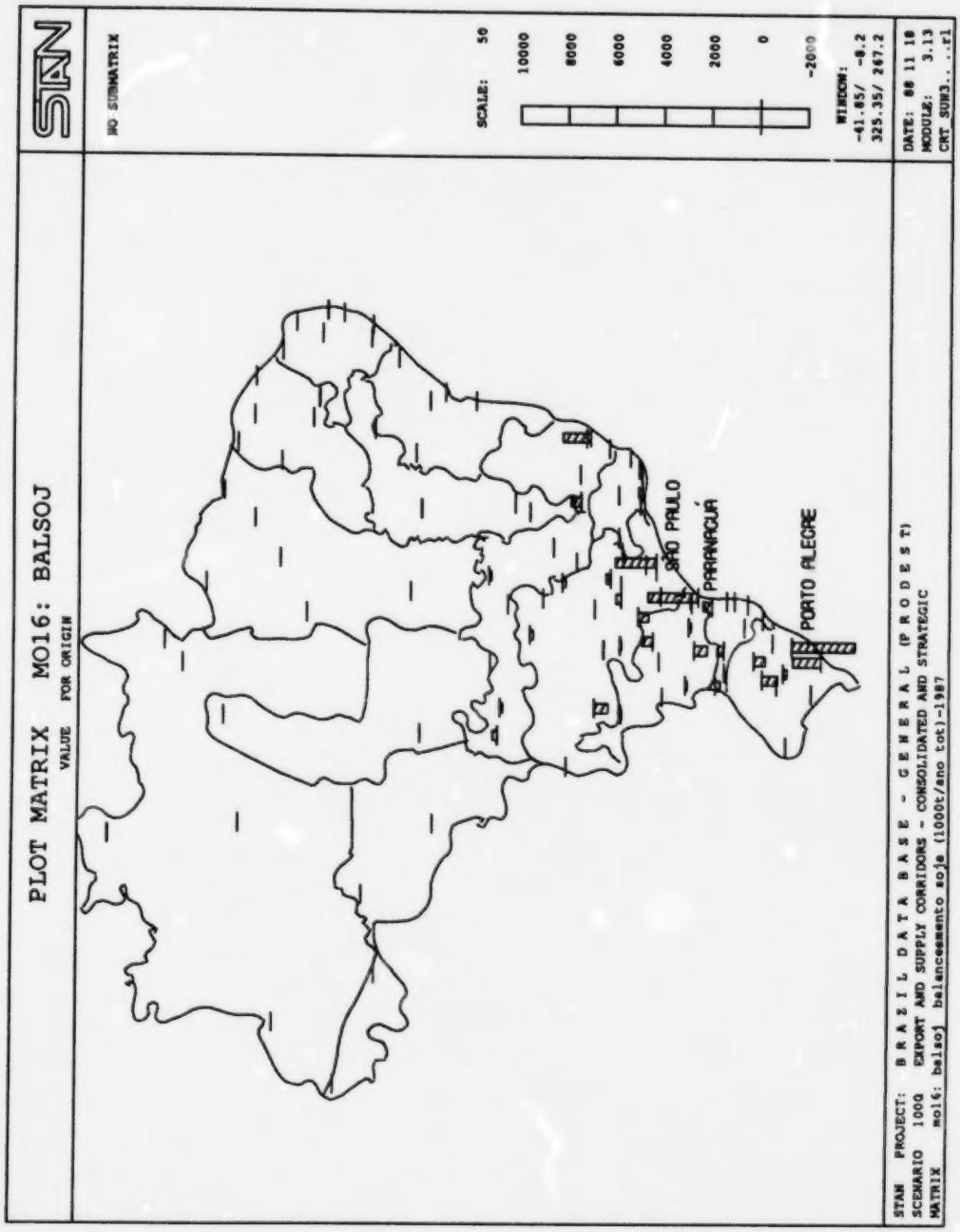

Figure 16 Soya Grain Supply-Demand Differences

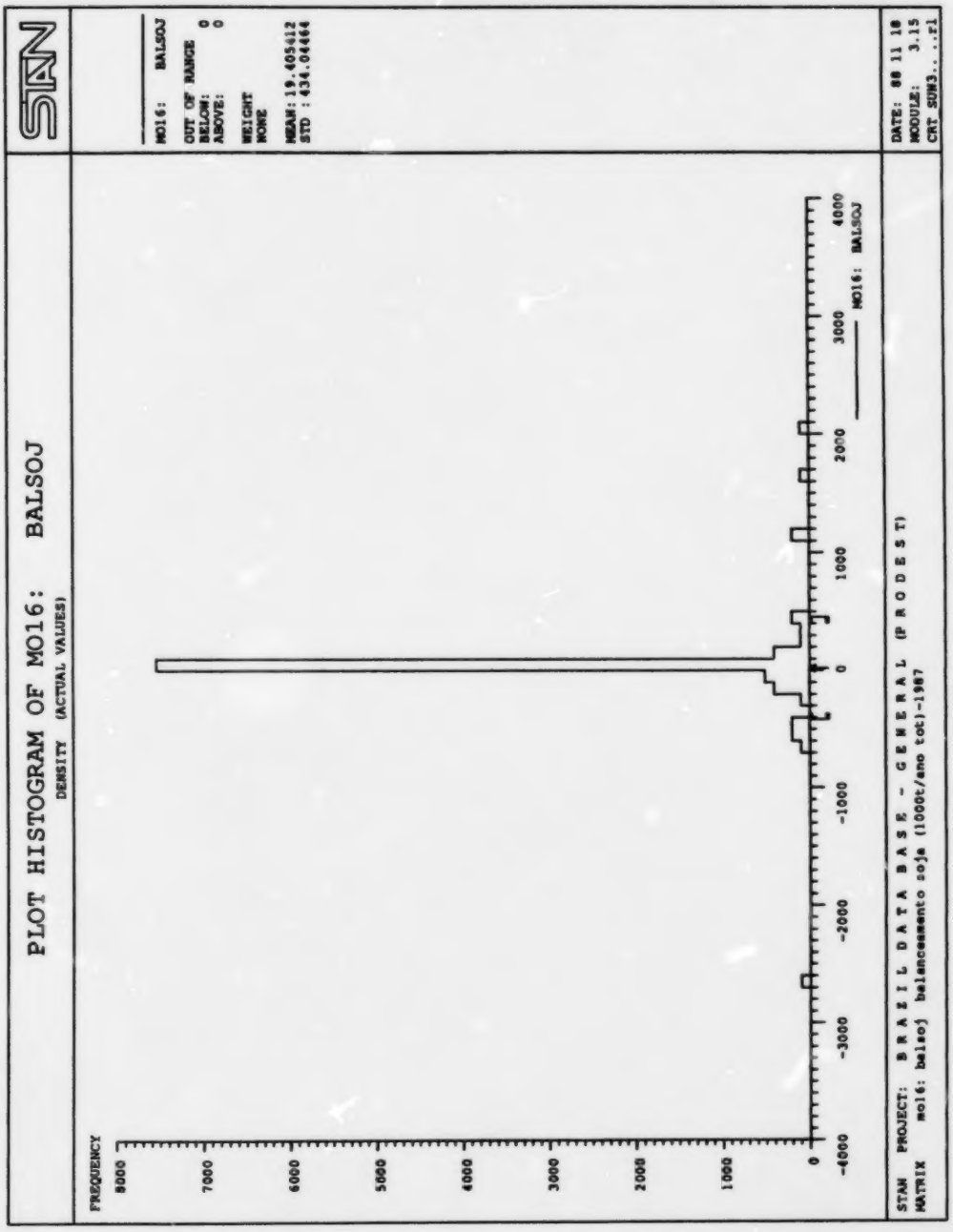

Figure 17 Histogram of Soya Grain Supply-Demand Differences

Several freight transportation scenarios were analysed by using this data base. The scenarios were designed to concord with the needs and priorities of the Ministry of Transportation and were concerned with increasing the productivity and efficiency of the transportation facilities, the adaptation of the transportation system to the requirements of the domestic and foreign market, the selection of the investment projects and improvements in the operation of the system as well as the control and reduction of fuel consumption in the transportation sector. Assignments were performed either by using several O/D matrices by product, reflecting an exogenous mode choice, or on the multimodal network according to a chosen measure of generalized cost.

Quantitative results, tabulated or listed in conventional reports, were useful for detailed cost, benefits and infrastructure utilization analyses. Of an equally great importance, for the instantaneous grasp of the situation and of the impact of the policies that were proposed, were the graphical representation of results. Plots of product flows in tons on the bare (Figure 18; this figure also indicates the selection of the window that appears in Figure 19) or base network proved useful. Besides product volumes, the corresponding unit costs or number of vehicules or convoys (Figure 20) were also ploted on the links and transfers of the network. The most useful graphical displays were, however, the plots of comparisons of scenarios, that vividly bring to life the impact of a specific policy or investment on the flow distribution and on the utilization of the infrastructure, when compared to the base year, for example. Comparisons of the product volumes or costs may be displayed on the links (Figures 21 and 22) or the transfers (Figure 23) of the network.

The STAN system proved to be an analysis tool of great use for the strategic planning of the transportation sector in Brazil. The application had a practical use, as it was integrated in studies that evaluated the feasibility of investment projects for

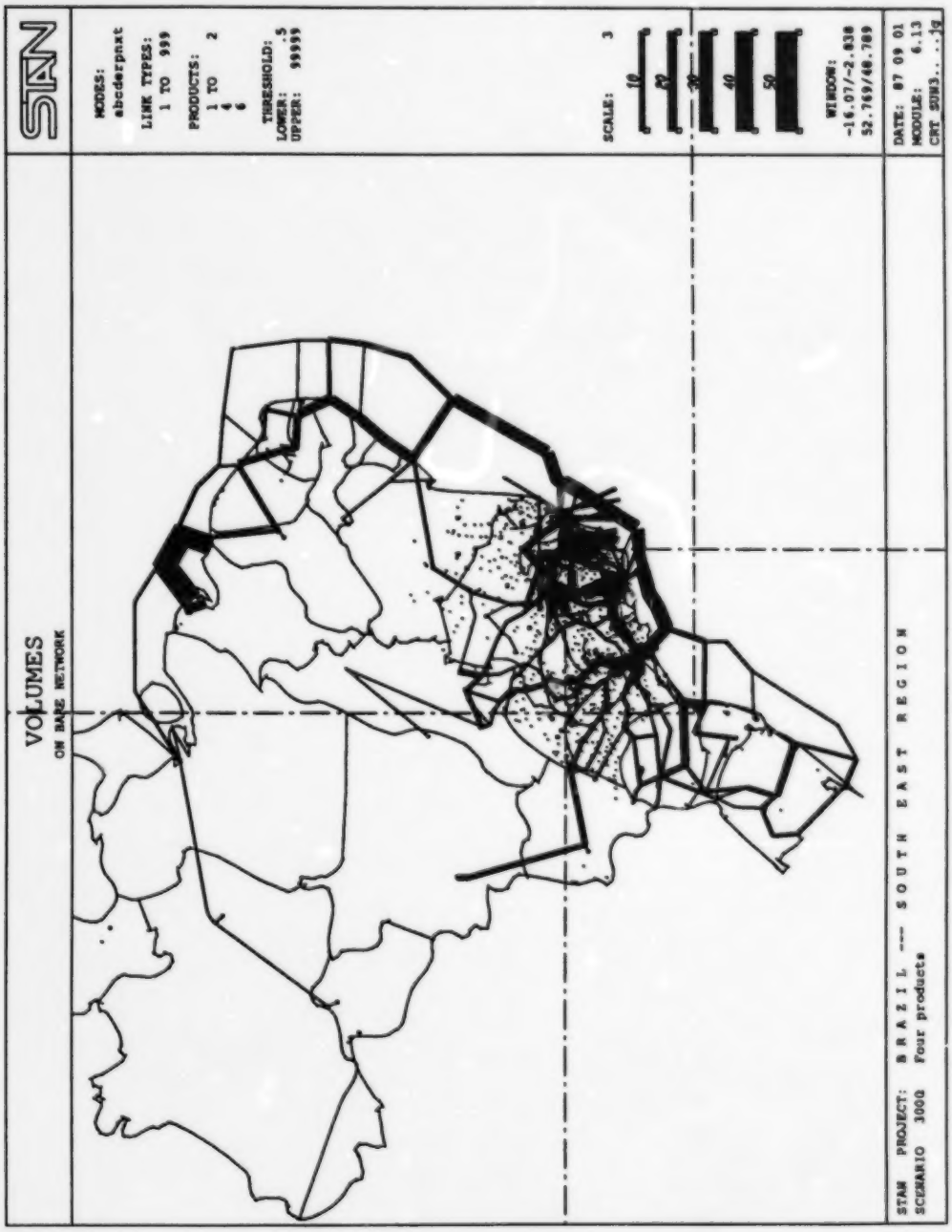

Figure 18 Plot of Total Link Flows

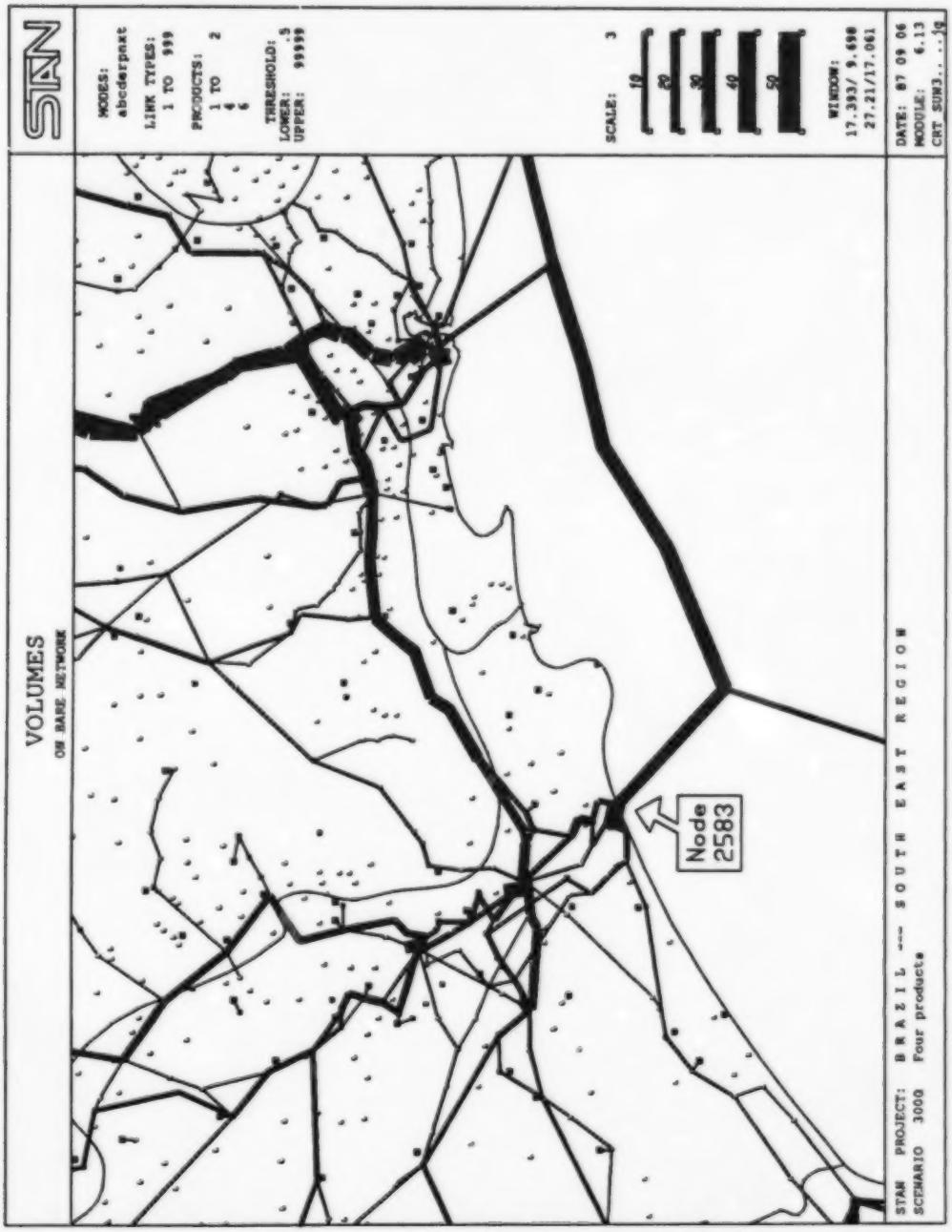

Figure 19 Window defined in Figure 18

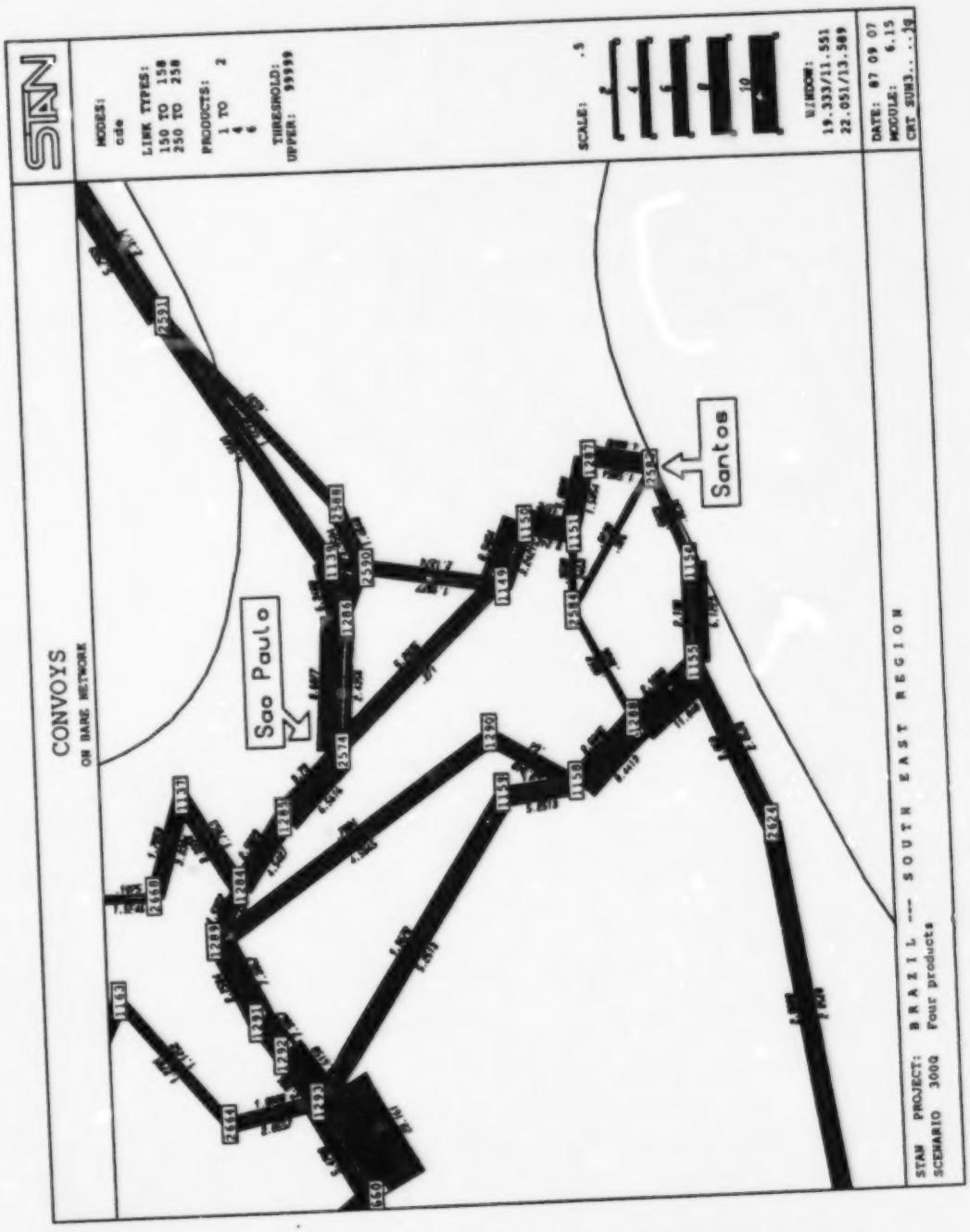

Figure 20 Total Number of Trains on a Selected Subnetwork

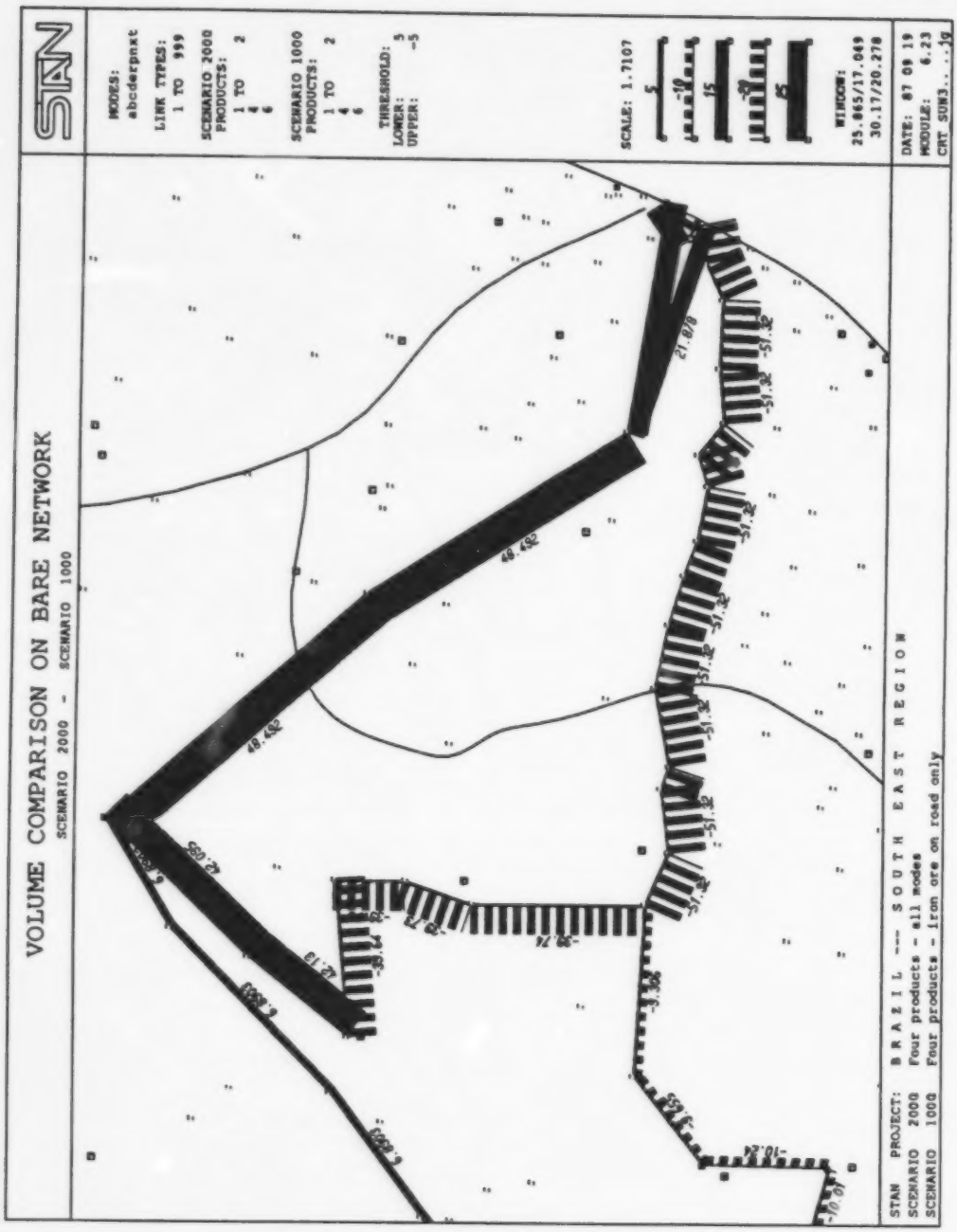
VOLUME COMPARISON ON BARE NETWORK
SCENARIO 2000 - SCENARIO 1000
STAN
MODES: abcderpnxt
LINK TYPES: 1 TO 999
SCENARIO 2000 PRODUCTS: 1 TO 2 4 6
SCENARIO 1000 PRODUCTS: 1 TO 2 4 6
THRESHOLD: LOWER: 5 UPPER: -5
SCALE: 1.7107
WINDOW: 25.865/17.049 30.17/20.278
DATE: 87 09 19
MODULE: 6.23
CRT SUN3...
STAN PROJECT: BRAZIL --- SOUTH EAST REGION
SCENARIO 2000 Four products - all modes
SCENARIO 1000 Four products - iron ore on road only

Figure 21 Volume Comparison on Bare Network

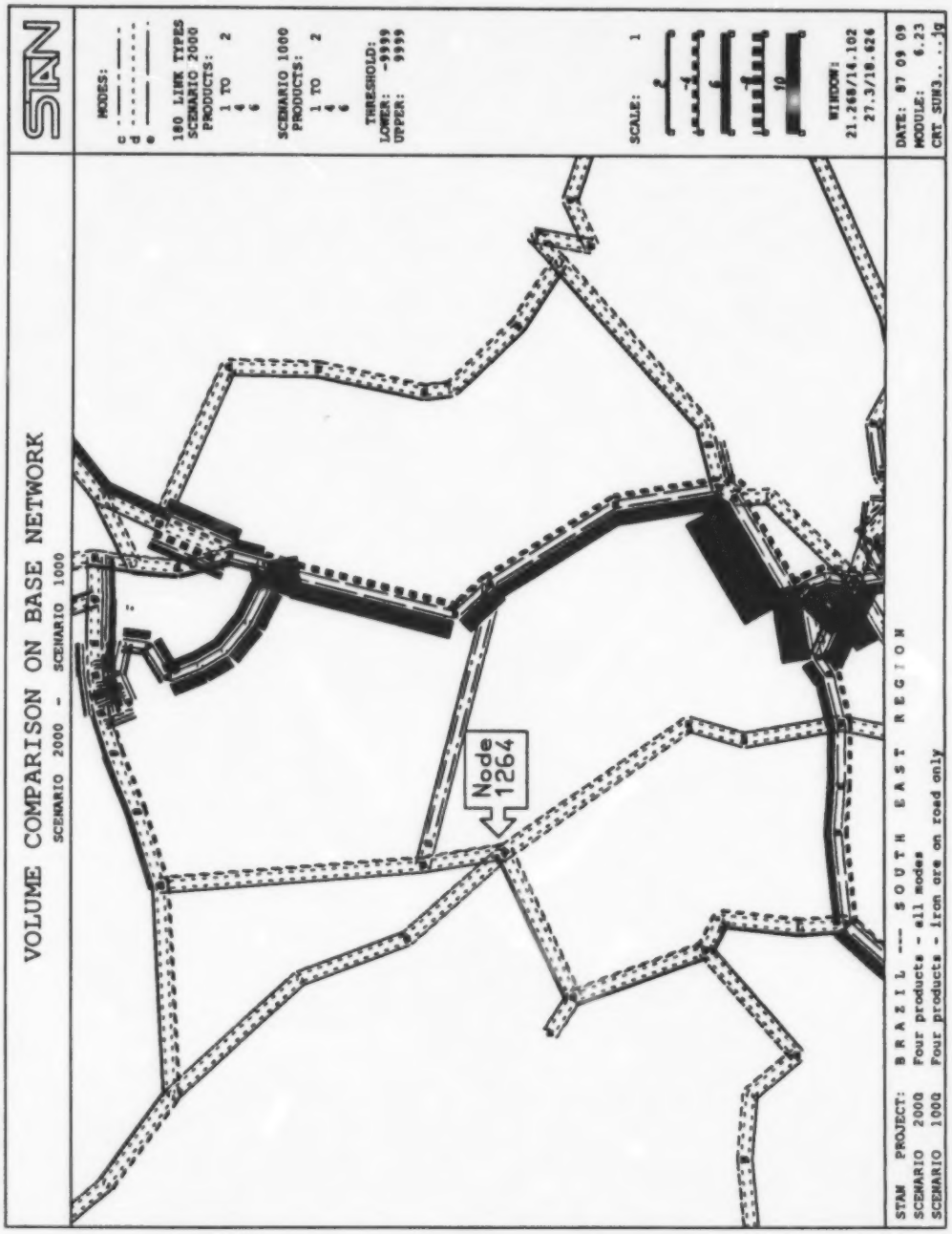

Figure 22 Volume Comparison on Base Network

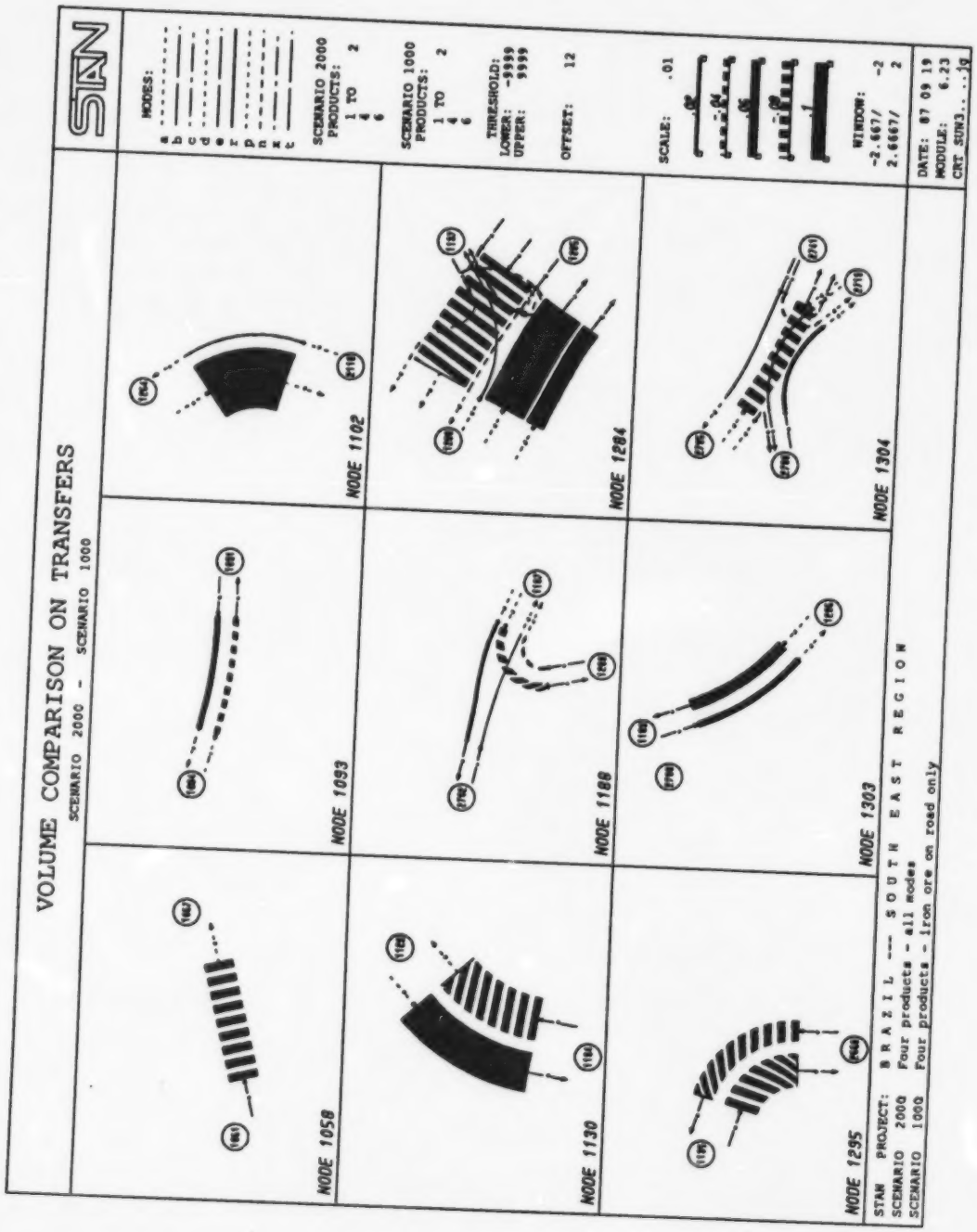

Figure 23 Volume Comparison on Transfers

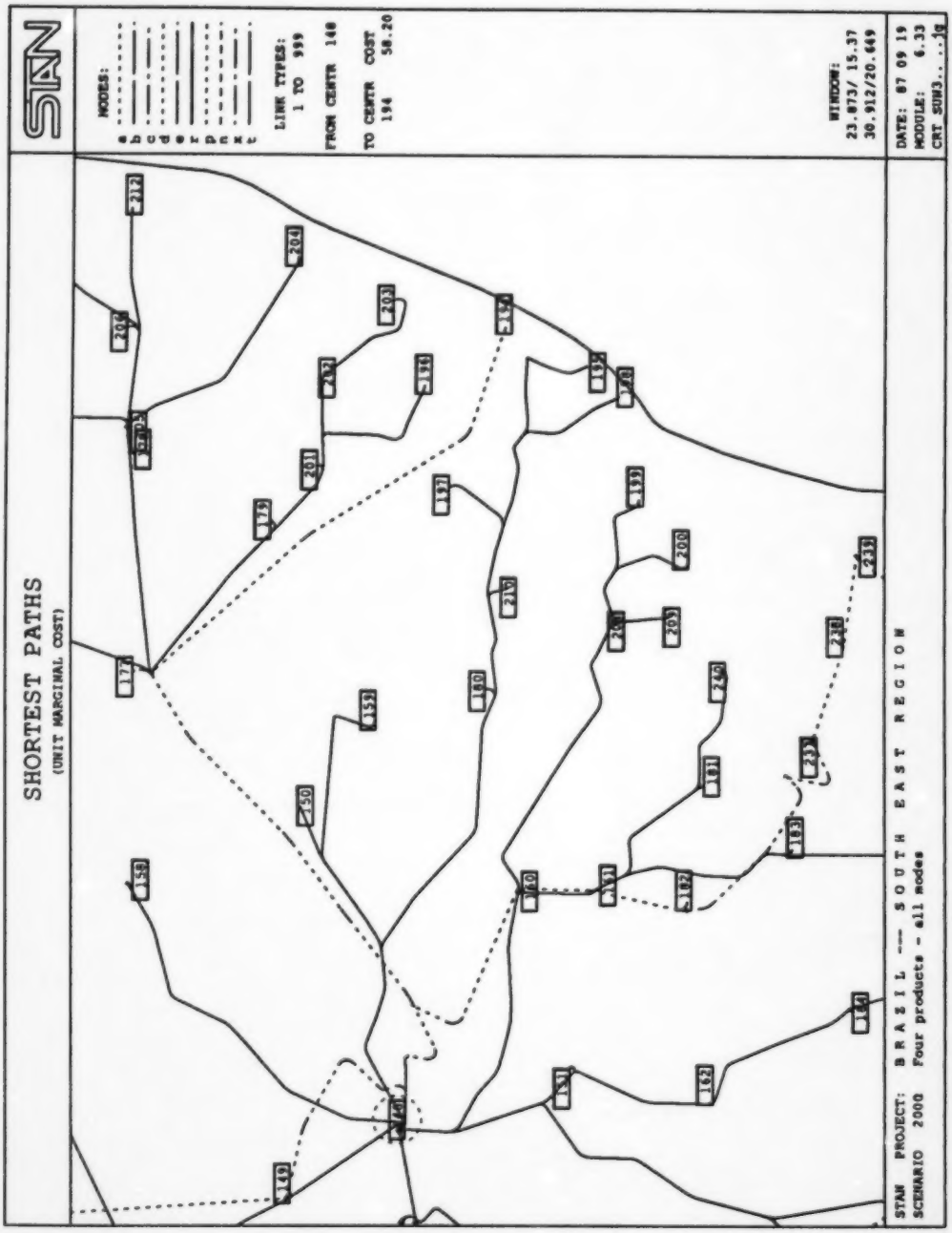

Figure 24 Unit Marginal Costs

upgrading the infrastructure and improve the operations and the energy consumption.

IV. THE STAN SYSTEM IN PERSPECTIVE

We conclude this presentation with a brief analysis of the main differences between STAN and other methods aimed at long range planning of transportation network, and with an enumeration of planned developments, both methodological and functional, of the system.

First, it is worth mentioning that although STAN is specifically designed for freight transportation, it is based to a large extent on the design of EMME/2, (4), (5), which is an interactive-graphic multimode method for urban and regional planning for the transportation of persons. In particular, the user interface and the *Matrix Editor* are similar to that used in EMME/2.

From a methodological point of view, our approach offers a modeling framework that is richer than most models previously proposed. See Guélat, Florian and Crainic (6), Crainic, Florian and Leal (2) and Crainic (3), for a more thorough discussion of this subject.

It is clear, however, that for strategic planning purposes, we do not seek the detail of a model that identifies shippers and carriers explicitly; rather we consider a model which is adequate for scenario comparisons when major investments are considered. Compared to the model of Friesz, Gottfried and Morlok (8), which is a formulation of breadth and scope similar to ours, we also assume an exogenous total demand by product but, unlike their model, our formulation does not yet include a carrier choice, or equivalently an endogenous mode choice component. We assume therefore that the shippers' behavior is reflected in the origin/destination matrices used and the specification of the mode choice, as remarked above. Note, however, that when specific

information is known concerning some shippers and their mode choice, this information may be introduced into our model by the proper definition of the permitted modal subset for the corresponding O/D matrix. The resulting flows are obtained by mode and no explicit information is available by carrier, unless a carrier and a mode coincide. In particular, we obtain the second component of the Friesz, Gottfried and Morlok model, which deals with the assignment of freight flows on carrier networks, by defining a mode for each carrier and by using the same functions and demand specification. Thus, the network model is much more refined as it allows detailed representation of the transportation infrastructure, facilities and services as well as the simultaneous assignment of multiple products on multiple modes, thus capturing the competition of products for the service capacity available, a feature which is of particular relevance when alternative scenarios of network capacity expansion are considered. While our aim is to provide a valid method for strategic planning at a national level, the model is sufficiently flexible to represent the transport infrastructure of one carrier only. In summary, the model that we propose provides a refined representation of a large multimode multiproduct transportation system for strategic planning purposes, but it may also be used to analyse the freight transportation carried out by a single carrier.

With respect to graphic displays and plots, one has also to consider the *Princeton Transportation Network Model and Graphic Transportation Model*, (9),(10), which provides relatively simple optimization procedures. However, one notes that this system does not offer a general modeling framework, since it consists of a very detailed representation of the North American Transportation network. As such, it is not adaptable to different contents and its scope is thus limitted.

An important characteristic of STAN is the fact that it is an "open" system, in the sense that new developments and enhancements may be added both to its

methodological core and to its functionality.

The STAN system is now implemented on personal computers equipped with Definicon co-processor boards and on SUN workstations, and is used by several organizations in Sweden, U.K., Finland, Spain and the U.S.A. It is planned that the system will also be implemented on personal computers based on the Intel 80386/80387 chips, and other computer platforms that emerge as technology advances. The feedback that we receive from the users and the progress in our own research leads us to define new research and development objectives, that result in enhancements of the system. We briefly mention some of them.

The basic model which is implemented in STAN assumes that the demand for transportation is specified for each product by a number of origin/destination matrices. However, many strategic analyses for freight networks take as given only the vectors of total supply and demand of products, at origins and destinations, respectively. This problem is particularly important for the analyses of transportation of raw materials, such as coal, where a customer is indifferent as to the origin of the product. Thus, an algorithm for the simultaneous determination of flows and demand matrices is being developed and will form the basis of a new module of STAN.

Another computational algorithm that will be provided by the STAN system is a multiproduct multimode maximum flow method (Part II of (1)). This facility allows the evaluation of the maximal amounts of certain commodities that can be transported with the existing transportation infrastructure and thus, may be very useful when considering major changes in demand.

The actual implementation of the model does not save the path information, due to memory considerations. However, this information is often required in transport analyses of particular origin-destination markets. We plan therefore to develop a method

that identifies the set of the used paths, for a given product and origin-destination pair, given the solution to the multimodal multiproduct network assignment problem. This method will be used as a posteriori analysis tool, and will use the path marginal cost information provided by the STAN assignment algorithm.

An algorithm that solves the classic transportation problem will also be added in the near future to the *Matrix Editor*.

The main enhancements planned for user interface functionality consists of a generalized link selection facility and a *Network Calculator*. These developments will allow access to subnetworks by any link attribute, predicted flows, etc., and in conjunction with the network calculator will provide a powerful tool for calibration, data validation and the implementation of various evaluation methods.

BIBLIOGRAPHY

1. Florian, M. and T.G. Crainic, (Editors), *Strategic Planning of Freight Transportation in Brazil: Methodology and Applications*, 5 volumes, Publications #638-642, Centre de recherche sur les transports, Université de Montréal, 1989.

2. Crainic, T.G., Florian, M. and J.E. Leal, *A Model for the Strategic Planning of National Freight Transportation by Rail,* forthcomming in **Transportation Science 23 (1)**, 1989.

3. Crainic, T.G., *An Interactive-Graphic System for the Analysis and Evaluation of Regional/National Transportation Networks*, **Transportation Networks and Regional Development**, U.S.S.R. Regional Science Association, May 23-26 1989, Leningrad, U.S.S.R., publication #632, Centre de recherche sur les transports, Université de Montréal, 1989.

4. Spiess, H., *Contributions à la théorie et aux outils de planification des réseaux de transport urbain,* Ph. D. thesis, département d'Informatique et de recherche opérationnelle, publication #382, Centre de recherche sur les transports, Université de Montréal, 296p., 1984.

5. Babin, A., Florian, M., James-Lefebvre, L. and H. Spiess, *EMME/2: An Interactive Graphic Method for Road and Transit Planning*, **Transportation Research Record** 866, pp 1-9, 1982.

6. Guélat, J., Florian, M. and Crainic, T.G., *A Multimode Multiproduct Network Assignment Model for Strategic Planning of Freight Flows*, forthcoming in **Transportation Science 23 (1)**, 1989.

7. Crainic, T.G., Florian, M., Guélat, J. and D. Larin, *STAN: User's Manual*, app. 600 pages, 1988.

8. Friesz, T.L., Gottfried, J.A. and Morlok, E.K., "A Sequential Shipper-Carrier Network Model for Predicting Freight Flows", *Transportation Science* **20**, 80-91, 1986.

9. Kornhauser, A.L., *Examples of Corporate Distribution and Transporation Planning Using the Princeton Transportation Network Model and Graphic Information System*, Civil Engineering Department, Princeton University, 1985.

10. Kornhauser, A.L., *Very Large Transportation Network Interactive Computer Graphic Information System and Problem Solver*, TIMS/ORSA Joint National Meeting, Boston, Civil Engineering Department, Princeton University, 1985.